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RESEARCH ARTICLE

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Hydrological characteristics of litter in different forest succession stages at Liuxihe Watershed, southern China

Abstract The hydrological characteristics of litter in four different forest succession stages, i.e., a *Pinus massoniana* forest, a mixed conifer and broad-leaved forest with conifer being the dominant species, a mixed conifer and broad-leaved forest with deciduous trees as dominant species, and an evergreen broad-leaved forest, have been studied by means of substituting space for time. The results show that while a community is developing to a zonal climax, the amount of litter becomes larger and its decomposition intensity becomes stronger; there is a positive relation between its water-holding capacity and velocity and its community maturity for the half-decomposed litter layer.

Keywords Liuxihe Watershed, forest succession, litter, hydrological characteristics

1 Introduction

It is generally known that a stand serves the function of rainwater holding and soil conservation. For a typical subtropical forest there are a number of layers, i.e., a forest canopy layer, a shrub layer, a herb layer, a moss layer, a litter layer, and a soil layer, each of which plays an important role during rainfall. Both the moss layer and the litter layer can weaken raindrop splashing the soil, hold rainwater, and delay and decrease water and soil erosion. Apart from these roles, the litter layer also plays a very important part in improving soil fertility (Solomon, 1976; West et al., 1981; Knapp, 1986; Ruan et al., 1999).

Changes in community structures are characteristic of a forest community succession (Kang et al., 2000; He et al., 2001a, 2001b; Zheng et al., 2005). Many scientists have studied forest community succession at Dinghushan, and have revealed the succession process and mechanism. The forest community succession in this area can be classified into three stages: conifer forests, mixed conifer and broad-leaved forests, and evergreen broad-leaved forests (Wang and Peng, 1985a, 1985b, 1987; Peng, 1996). With little or no interference, both mass and net primary productivity increase when a forest community succession approaches a climax (Yang et al., 2003). The relationship between the hydrological characteristics of litter and the maturity of a forest community in succession has not been reported as yet. For four forest communities in succession, i.e., a *Pinus massoniana* forest, a mixed conifer and broad-leaved forest with conifer being the dominant species, a mixed conifer and broad-leaved forest with deciduous trees as the dominant species, and an evergreen broad-leaved forest, the hydrological characteristics of litter at different stages of forest succession have been studied and we present our results.

2 Materials and methods

2.1 Forest stands

Our study area was located at the Liuxihe Watershed in Conghua, Guangzhou (23°32′–23°50′N, 113°45′–113°54′E). This watershed originates from the Conghua undulating mountainous region. The watershed area is about 2300 km^2 with a 156-km-long passage through Liangkou, Jiekou, Beixing, Huadong, and Guangzhou, which finally ends in the Zhujiang River.

A south Asia subtropical wet monsoon climate dominates this area with characteristics of a rainy season from

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April to September and a dry season from October to March. Annual precipitation is about 2866.5 mm with a minimum of 1280.7 mm, relative humidity of 79%, and annual temperature of 20.3°C. The soil is a yellow earth in the southeast watershed area with granite, quartzite, and shale as parent material, and the rest of the area is red earth or red-yellow earth. The soil is not very fertile with high acidity. The forest coverage is over 85%.

The succession of a forest community in the Liuxihe Watershed follows its own natural rules (Peng, 1996). Although *P. massoniana* forests grow very fast under forest tending and when closed to farmers, a *P. massoniana* mature stand has a simple structure and low coverage, with sunlight passing through the canopy and large differences in day and night temperatures. Because of these features many shade-intolerant tree species, for instance *Castanea henryi* and *Schima* spp., can invade *P. massoniana* stands very easily and grow very well. As more and more shade-intolerant tree species invade, both coverage and shade increase and many *P. massoniana* trees die out one by one, naturally. As a result, the community becomes more and more complex in species composition and structure, and more and more mildly tolerant broad-leaved trees invade and replace *P. massoniana* trees. This process of forest succession can be expressed by the dynamic characteristics of dominant populations in a stand, and the community tends to become a zonal climax community with mildly tolerant broad-leaved trees (e.g., *Cryptocarya concinna* and *Cryptocarya* spp.) as dominant species. The processes of forest succession in the Liuxihe Watershed can be divided into six stages as shown in Table 1.

In order to monitor the relation between forest community succession and the hydrological characteristics of its litter, four typical forest communities have been studies in this watershed.

These four forest communities are a *P. massoniana* forest (CA), a mixed conifer and broad-leaved forest with conifer trees as the dominant species (CB), a mixed conifer and broad-leaved forest with shade-intolerant trees as the dominant species (CC), and a mixed evergreen broad-leaved forest with mildly tolerant broad-leaved trees as the dominant species (CD). These four communities are at different stages in succession and their basic information is shown in Table 2.

2.2 Material

These typical forest communities CA, CB, CC, and CD in the Liuxihe Watershed were plotted for research, and original litter in the different communities was collected as experimental material (Table 2).

2.3 Methods

2.3.1 Litter collection

In each typical community a plot was established of size 10 m×10 m and replicated two to three times according to the stand situation. In each plot three small plots were established as well for litter collection with dimensions 20 cm×25 cm at the upper, middle, and lower parts of the slopes. Before litter collection, the fresh litter layer and half-decomposed litter layer was divided and their thickness measured. Litter from the various conditions was put in different boxes. Litter from the fresh layer retained its original morphological state of leaves and branches, while litter from the half-decomposed layer also kept its original morphological state of leaves and branches. This could be recognized by simple observation but it had decayed to a certain extent.

Table 1 Succession process of forest community in Liuxihe watershed area

typical vegetation	succession process					
	stage 1	stage 2	stage 3	stage 4	stage 5	stage 6
forest vegetation	coniferous forest	mixed conifer and broad-leaved forest with conifer trees being the dominant species	mixed conifer and broad-leaved forest with shade-intolerant trees being the dominant species	mixed evergreen broad-leaved forest with shade-intolerant trees being the dominant species	mixed evergreen broad-leaved forest with mid-tolerance broad-leaved trees being the dominant species	zonal climax community with mid-tolerance broad-leafed tree species
forest formation	*P. massoniana* forest	*P. massoniana-Castanea henry-Castanea* spp.	*Castanea henryi-Castanea.* spp. -*P. massoniana*	mixed evergreen with *Castanopsis fissa* being the dominant species	*Cryptocarya concinna-Castanea henryi-Cryptocarya* spp. *Castanea* spp.	*Cryptocarya concinna-Cryptocarya* spp.

Table 2 Basic information of different forest communities in study area

community type	elevation/m	slope/°	location	canopy density/%	forest age	height/m	DBH/cm
CA	223	35	west	70	middle-age forest	12.7	19.9
CB	244	40	southeast	72	middle-age forest	15.3	29.4
CC	240	30	southwest	80	mature forest	16.5	20.5
CD	251	30	southwest	90	mature forest	17.4	30.5

2.3.2 Water-holding amount and water absorption rate of litter

Litter amount: the amount of litter was weighed in units of t/hm^2 after drying the litter in an oven. Litter water-holding characteristics: the weighed litter was put directly into a soil sieve and immersed in water. The wet litter was weighed every 2 h over a period of 20 h. In this way, the water-holding capacity and water absorption rate could be calculated from the differences between the dry and wet litter weights. The unit of water-holding amount was changed into units of mm, given the area of the litter plots.

From these data, we could find both the relation between the water-holding amount and the immersion time, as well as the water absorption rate and immersion time with various functions, i.e., linear, power, exponential, logarithmic, quadratic, an S-curve, and polynomial regressions. We tested the regression equations at the 95% or 99% confidence level (Cui et al., 2005; Su et al., 2007).

3 Results and analysis

3.1 Amount of litter and components of different forest communities

The type, components, amount, and rate of decomposition of litter change with community type, age, canopy density, and so on, while the hydrological efficiency of litter depends on its type, amount, component, and the degree of decomposition as well. The litter in our study was composed of about 70%–85% leaves and 15%–30% branches and raw bark.

Considering that litter moisture varies with the seasons, the litter collected from the plots was dried in an oven before being weighed. The amount of litter was changed into units of t/hm^2 according to the area of the litter plots. The results are presented in Fig. 1.

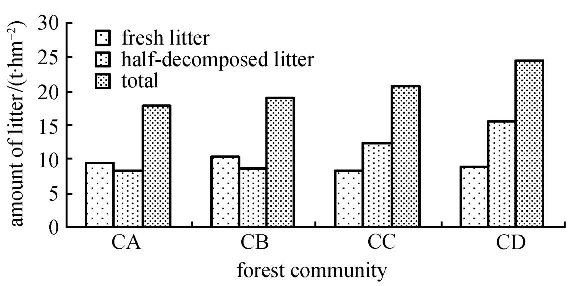

Fig. 1 Amount of litter in different forest communities

The results of Fig. 1 indicate that when a community succession goes to its zonal climax, the amount of litter increases. Without disturbance by people, the amount of litter increases with canopy density and the age of a stand. The structure of the canopy is the main factor affecting the amount of litter in a stand. The *P. massoniana* forest is at a pioneer stage and characterized by a simple canopy structure, simple litter components, and low canopy density. As the succession proceeds, communities become characterized by more complex canopy structures, greater canopy density, more diverse litter components, and larger amounts of litter.

3.2 Comparative analyses of degree of litter decomposition

The degree of litter decomposition is a very important characteristic and determines the amount of litter in a stand. In Table 3, A represents the amounts of fresh litter and B the mount of half-decomposed litter. The degree of litter decomposition can be estimated by both $L_a=\frac{A}{B}\times 100\%$ and $L_b=\frac{B}{A+B}\times 100\%$.

Table 3 shows that for $L_a=\frac{A}{B}\times 100\%$ the maximum relative amount of litter is found in *P. massoniana* forest (CA), followed by the mixed conifer and broad-leaved forest (average of CB and CC), the minimum being the mixed evergreen broad-leaved forest with mildly tolerant broad-leaved trees as the dominant species (CD); for $L_b=\frac{B}{A+B}\times 100\%$ the maximum is mixed evergreen broad-leaved forest with mid-tolerant broad-leaved trees being the dominant species (CD), followed by mixed conifer and broad-leaved forest (average of CB and CC), the minimum being *P. massoniana* forest (CA). The larger the ratio $\frac{B}{A+B}\times 100\%$, the larger the intensity of litter decomposition.

Table 3 Litter decomposition intensity in different community types

community type	amount of litter in a layer			
	A/(t·hm^{-2})	B/(t·hm^{-2})	$\frac{A}{B}$/%	$\frac{B}{A+B}$/%
CA	9.61	8.29	115.92	46.31
CB	10.43	8.55	121.99	45.05
CC	8.38	12.31	68.07	59.50
CD	8.83	15.57	56.71	63.81

Because of the special climate in a mixed evergreen broad-leaved forest with mildly-tolerant broad-leaved trees as the dominant species (CD) and low C/N, it is very good for aerobic microbes. As a result, litter is decomposed very quickly, and the amount of fresh litter is very small. By contrast, *P. massoniana* forest litter is characteristic of needle and cones components that are very hard, rich in rosin and high C/N, so *P. massoniana* forest litter is very difficult to decompose.

3.3 Water-holding amount of litter in different succession communities

With porous and loose characteristics, litter can hold a large amount of rainwater. The water-holding capacity of litter can be calculated by the ratio of water-holding amount to dry litter weight. When it is saturated, it is called saturated water content. The ecological effect can be estimated from the amount of litter and the amount of water it holds.

Table 4 indicates that there are differences among the four forest communities in the maximum water-holding capacity of the fresh litter layer, the half-decomposed litter layer, and total litter layer.

For the fresh litter layer, the water-holding capacity of the mixed evergreen broad-leaved forest with mildly tolerant broad-leaved trees as the dominant species (CD) is maximum with 197.33%, *P. massoniana* forest (CA) the second with 181.12%, mixed conifer and broad-leaved forest with shade-intolerant trees being the dominant species (CC) next with 176.28%, and mixed conifer and broad-leaved forest with conifer trees being the dominant species (CB) the least with 171.73%. The order of water-holding capacity is CB (1.64 mm)>CA (1.62 mm)>CD (1.46 mm)>CC (1.27 mm).

For the half-decomposed litter layer the order of the water-holding capacity is CD>CC>CB>CA because of the differences in the amounts of litter.

For the total litter the order of water-holding capacity is CD (3.21 mm)>CB (3.02 mm)>CC (2.91 mm)>CA (2.76 mm) in order. In general, maximum water-holding capacity of fresh litter layers is larger than that of half-decomposed litter layers.

3.4 Water-holding characteristics of different communities

The water-holding capacity of litter is related not only to both litter components and degree of decomposition, but also to the moisture content of litter.

3.4.1 Relationship between water-holding capacity of litter and immersion time

From the data of immersion time and water-holding capacity, a logarithm regression has been fitted for both the fresh litter layer and half-decomposed litter layer in the four communities:

$$S = K\ln t + P$$

where S is water-holding capcity, t the immersion time, K a coefficient, and P a constant. Both K and P for the four forest communities are shown in Table 5.

From Figs. 2 and 3, we can see that the water-holding capacity of litter for both the fresh and the half-decomposed litter layers in each community varies rapidly in the first eight hours of immersion, but it varies slowly afterwards.

3.4.2 Relationship between water absorption rate and immersion time

From the data of immersion time and water absorption rate, a power function has been fitted by means of regression analysis for both the fresh and the half-decomposed litter layers in the four communities:

$$V = \Phi t^{-\varepsilon}$$

Table 4 Comparison of water-holding capacity of litter in different community types

community type	amount of undecomposed litter			amount of half-decomposed litter			total		
	litter amount /($t\cdot hm^{-2}$)	maximum water-holding rate/%	maximum water-holding/mm	litter amount /($t\cdot hm^{-2}$)	maximum water-holding rate /%	maximum water-holding /mm	litter amount /($t\cdot hm^{-2}$)	maximal water-holding rate /%	maximal water-holding /mm
CA	9.61	181.12	1.62	8.29	168.17	1.13	17.91	174.64	2.76
CB	10.43	171.73	1.64	8.55	166.03	1.38	18.98	168.88	3.02
CC	8.38	176.28	1.27	12.31	155.89	1.64	20.69	166.08	2.91
CD	8.83	197.33	1.46	15.57	151.64	1.75	24.40	174.49	3.21

Table 5 Regression equation parameters

forest community	fresh litter layer				half-decomposed litter layer			
	K	P	Φ	ε	K	P	Φ	ε
CA	0.1892	1.0782	1.0778	0.8512	0.0748	0.9091	0.9093	0.9245
CB	0.1584	1.1977	1.1969	0.8833	0.0887	1.1166	1.1167	0.9268
CC	0.1263	0.9021	0.9021	0.8778	0.0911	1.3483	1.3480	0.9372
CD	0.1822	0.9446	0.9427	0.8375	0.1103	1.4257	1.4246	0.9279

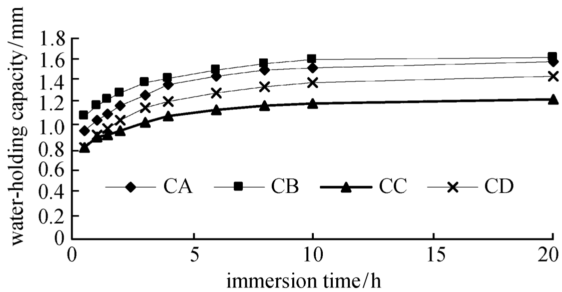

Fig. 2 Relationship between water-holding capacity of fresh litter and immersion time

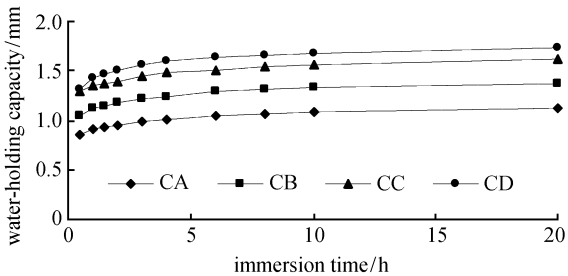

Fig. 3 Relationship between water-holding capacity of half-decomposed litter and immersion time

where V is the rate of water absorption, t the immersion time, Φ a coefficient, and ε an exponent. Both Φ and ε for the four forest communities are shown in Table 5.

From Figs. 4 and 5, we can see that the water absorption rate of litter for both the fresh and the half-decomposed layers in each community varies rapidly in the first two hours of immersion and then varies less obviously six hours later and remains steady at 10 hours. The water-holding capacity is saturated in ten hours of immersion.

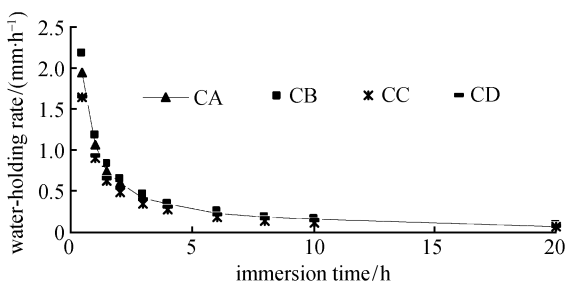

Fig. 4 Relationship between the water-holding rate of fresh litter and immersion time

3.5 Relationship between water-holding capacity of litter layer and rain

The maximum water-holding capacity of the litter in the *P. massoniana* forest (CA) is 2.76 mm, that of the mixed conifer and broad-leaved forest with conifer trees as the

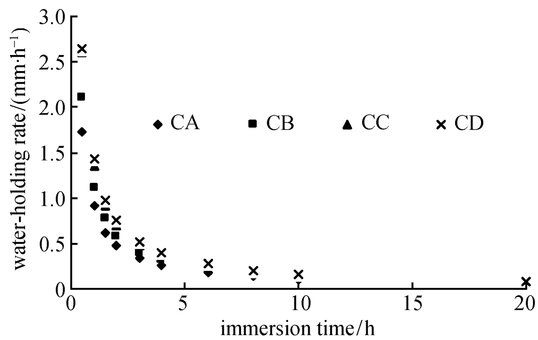

Fig. 5 Relationship between the water-holding rate of half-decomposed litter and immersion time

dominant species (CB) 3.02 mm, for the mixed conifer and broad-leaved forest with shade-intolerant trees as the dominant species (CC) 2.91 mm, and for the mixed evergreen broad-leaved forest with mildly tolerant broad-leaved trees as the dominant species (CD) 3.21 mm. The maximum water absorption rates of litter for CA, CB, CC, and CD are 3.66, 4.29, 4.25, and 4.28 mm/h, respectively. When the throughfall is less than that of water-holding capacity, all throughfall is absorbed by the litter layer. When the throughfall is less than 2.76 mm and throughfall intensity is less than 3.66 mm/h all throughfall water will be absorbed by the litter layer kept at its original state and no surface water erosion and water infiltration into soil will occur in the CA stand. All other communities maintain the same relative throughfall and relative throughfall intensity; the throughfall and throughfall intensity are 3.02 mm and 4.29 mm/h for CB, 2.91 mm and 4.25 mm/h for CC, and 3.21 mm and 4.28 mm/h for CD, respectively.

4 Discussion

As a plant community proceeds slowly along its path to a zonal climax, the amount of litter increases, but litter decomposes more easily. The amount of half-decomposed litter is more than the amount of fresh litter in the four forest communities studied, except for the *Pinus massoniana* forest, a result consistent with other investigators (Cui et al., 2005; Su et al., 2007).

Although both the water-holding capacity and the water absorption rate of half-decomposed litter layer increase while a plant community succession proceeds to its zonal climax, the fresh litter layer does not follow this tend. For both regression equations $S = K\ln t + P$ and $V = \Phi t^{-\varepsilon}$, their correlation coefficients are larger than 0.98 ($p < 0.01$). This means that the relation between the water-holding capacity and the immersion time fits a logarithm regression equation and that of the water absorption rate and the immersion time fits a power function. Except for ε, the values of the three parameters K, P, and Φ of the half-decomposed litter layer increase as succession proceeds in the direction of a zonal climax. These parameters themselves can reflect different hydrological characteristics of the various litter layers in the four forest communities.

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