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STOCK AND HYDROLOGICAL CHARACTERISTICS OF FOUR LIMESTONE SECONDARY FOREST LITTERS IN SUBTROPICAL CHINA

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Abstract

Forest litter plays an important role in water conservation, which has obvious effects on water storage and preservation. Taking four types of limestone forests in Guilin in the subtropical region as the object, the existing amount of litter in subtropical limestone forests was investigated *via* field sampling, and the hydrological effect of litter was explored using the water soaking method. The amount of litter accumulated in the four forests was 4.64–8.29 t·hm^{-2} (p<0.05), and the accumulation of the undecomposed layer of litter was greater than the semi-decomposed layer. The maximum water-holding capacity of litter was 11.53–16.05 t·hm^{-2} (p<0.05), *Cyclobalanopsis glauca* forest was the largest, *Platycarya strobilacea* forest was the smallest. The water-holding capacity and soaking time of the four forest litters had a logarithmic function relationship (R^2 > 0.95, p = 0.00), whereas the water absorption rate and soaking time had a power function relationship (R^2 > 0.9994, p = 0.00). The effective interception volume and effective interception depth of the four forest litters were represented by the *C. glauca* forest (127.71 t·hm^{-2}), deciduous mixed forest (114.35 t·hm^{-2}), *P. strobilacea* forest (97.21 t·hm^{-2}), and evergreen mixed forest (86.86 t·hm^{-2}) (p<0.00), which was equivalent to intercepting precipitation of 12.77, 11.44, 9.71, 8.69 mm (p<0.00), respectively. The *C. glauca* forest had the strongest interception ability and the evergreen mixed forest had the weakest. The existing amount of litter and hydrological functions of the four forests indicated that the *C. glauca* forest had strong water conservation ability. It is recommended to enhance the protection and restoration of the *C. glauca* forest in the limestone area of Guilin or other areas with similar climate and environment.

Key words: Limestone; Litter; Existing quantity; Hydrological effect; Forests.

Introduction

China's subtropical limestone area is one of the largest contiguous limestone area in the world. The vegetation in this area has been damaged by human activities for a long time, and the forest is very little preserved, but it plays a key role in maintaining the biodiversity and ecosystem functions in this area (Li *et al*., 2018). The strongly developed epikarst zone causes the precipitation to move rapidly and is prone to geological drought, which is an important reason for the fragility of the karst environment (Li *et al*., 2018). As the main link between material circulation and energy flow in the forest ecosystem, litter plays unique ecological functions and is the second active layer of forest hydrological effects (Moazzam *et al*., 2018; Zhou *et al*., 2018; Arnim *et al.*, 2019). It can conserve water resources, reduce soil erosion, and effectively reduce the consumption of soil water by solar irradiation. It plays a significant role in regulating surface runoff. It can be said that it is not only an important nutrient source, but also has significant environmental benefits (Lin *et al*., 2004; Pan *et al*., 2004; Liu *et al*., 2019; Wang *et al*., 2019).

The research on the hydrological effects of litter was aimed at exploring the relationship between the existing amount of litter in different forest types and the water holding and regulation capacities of different decomposed layers, on the one hand (Bart *et al*., 1992; Huang *et al*., 2020; Bohara *et al*., 2020; Liu *et al*., 2016), and the relationship between litter and some terrain conditions are combined, such as the effect of slope position, slope surface, slope shape, soil, altitude, etc., on the hydrological process of litter and the role of litter in soil and water conservation (Liu *et al.*, 2018a; Zeng *et al.*, 2018; Fu *et al.*, 2019; Walter *et al*., 2020). In recent years, the research on the storage of plant litter and water conservation has mainly focused on the ecological critical zone, such as the natural forest ecosystem in the nature reserve and the alpine tundra ecosystem. (Pang *et al*., 2017; Li *et al*., 2017; Hou *et al*., 2018; Liu *et al*., 2018b). Limestone area is one of the main ecological critical zone. It has a land with abundant bare rocks and scarce and dincontinuous soil, and it is extremely prone to rock desertification and soil erosion (Li *et al*., 2018). However, there are few research reports on the storage capacity of litter and its hydrological effects in limestone areas (Wei *et al*., 2017; Cai *et al*., 2021).

As a typical subtropical limestone region, Guilin City in Guangxi has developed typical karst landforms and river valleys. Barren soil makes it difficult for trees to grow. *Cyclobalanopsis glauca*, *Cornus wilsoniana* and *Fraxinus griffithii* and *Platycarya strobilacea* are typical tree species in the karst area. Under natural conditions, it is easy to form four typical forests, such as Evergreen broadleaf forest with monodominant species *C. glauca*, mixed evergrenn and deciduous broadleaf forest dominated by evergreen trees and deciduous trees respectively, and deciduous broadleaf forest with monodominant species *Platycarya strobilacea*. These four typical karst forests make great contributions to land cover and soil and water conservation in this area, provide a good ecological environment and provide good ecosystem functions for this area. The forest vegetation in this area is mainly of *C. glauca* forest and its derivative forests. It also has the highest economic value in this area. Therefore, studying the litter in the *C. glauca* forest and its hydrological characteristics in the limestone area of Guilin is of great significance to the sustainable development of the limestone area in this city.

In this study, combining field sampling and laboratory experiment analysis, we conducted a preliminary discussion on the litter deposits and hydrological effects of four typical forest types in the limestone area of Guilin. Does the litter stock of the other three mixed forests larger than that of the pure *C. glauca* forest due to the diversity of the constituent tree species? Does the deciduous mixed forest have more existing stocks than the evergreen mixed forest? Because of the complexity of the species, we hypothesized that the water conservation capacity of the three mixed forests was higher than that of the single species *C. glauca* forest. This research will serve as a reference for ecological environment construction, such as forest maintenance, forest protection, forest ecological and hydrological function evaluation, and soil erosion control in limestone areas.

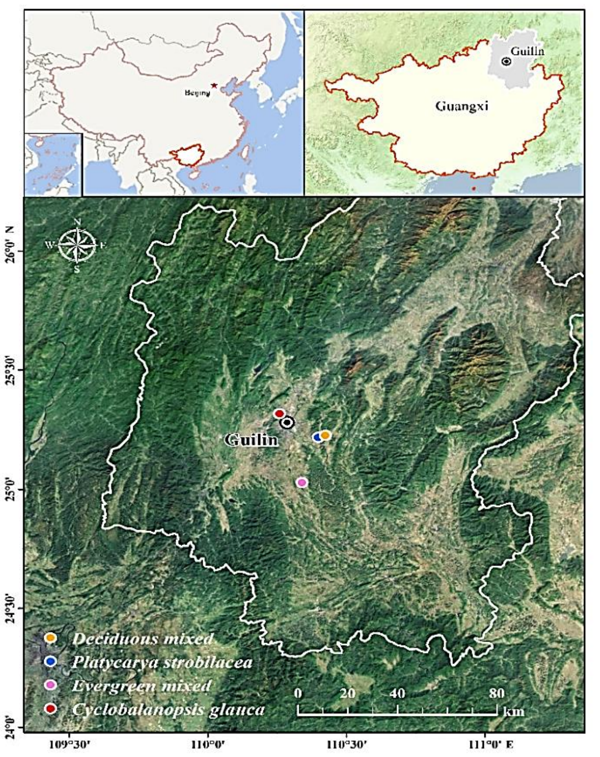

Fig. 1. Map of forest and sampling points in Guilin, Guangxi, China.

Materials and Methods

Overview of the study area: The study area is located in the suburbs of Guilin, Guangxi, China (25°20′N, 110°18′E) in Fig. 1. It is a typical limestone landform and belongs to the subtropical monsoon area. Affected by climate and terrain, the area is mild and rainy, with an average annual temperature of 19.63 ° C, average temperature of 25.5°C in the summer (May to October), and average temperature of 12.8 ° C in the winter (November to April). The frost-free period is 300 days, the average annual precipitation is 1939 mm, and the average annual relative humidity is 75%. The rainy season is from April to July, and the annual precipitation rate is 64.90%. Conversely, the dry season is from November to February, and the rate of rainfall is only 14.73% for the whole year. The lithology of the study area is as follows: limestone, brown lime soil, surface rock exposure rate of 35% to 65%, and incompletely covered soil. To study the amount of litter and its hydrological effects on the different vegetation types in limestone areas, four typical limestone forest plots were selected in the suburbs of Guilin. The detailed information of the four forest plots is presented in (Table 1).

Determination of existing litter and natural moisture content: Five small squares with a size of 50 × 50 cm were randomly selected according to the different slopes in the standard sample plots of different forest stands. The litters in the small squares were picked up and then put into plastic bags and brought to the laboratory. Subsequently, they were categorized into decomposed and undecomposed, and weighed (fresh weight, M_1). After drying to constant quality at 80°C, reweighed (dry weight M_2). The natural moisture content of the litter was calculated using the following formula:

$$R_0 = (M_1 - M_2)/M_2 \times 100\% \quad (1)$$

where R_0 denotes the natural moisture content of the litter (%); M_1, the mass before drying (g); and M_2, the mass after drying (g).

Determination of the water-holding capacity and water absorption rate of the litter: The water-holding capacity and water absorption rate of the litter were measured *via* immersion (Xu *et al*., 2009). Dried litter was divided into four parts, weighed, and put into 80-hole nylon bags. After soaking for 5 min, 10 min, 20 min, 40 min, 1 h, 2 h, 4 h, 8 h, 16 h, 24 h, the litter was taken out and suspended and then left to stand until dripping stopped. The litter was weighed again, and the average was obtained. Subsequently, the water-holding capacity and water absorption rate at different soaking times were calculated using the following formula:

$$\Delta M = M_t - M_0 \quad (2)$$

$$V_t = (M_t - M_0)/t \quad (3)$$

$$R_t = (M_t - M_0)/M_0 \times 100\% \quad (4)$$

where ΔM denotes the water-holding capacity of the litter soaked t hour ($t \cdot hm^{-2}$); V_t, the water absorption rate of the soaked t hour ($t \cdot hm^{-2} \cdot h^{-1}$); R_t, the water-holding capacity (%); M_t, the weight (g) of soaking t hour; M_0, the dry weight of the litter (g); and t, the soaking time (h).

Table 1. Overview of the study plots. The location of the four forest litters and hydrological effect of the experimental plots, ve getation, soil, and other environmental factors in Guilin.

Forest type	*Cyclobalanopsis glauca*	Deciduous mixed	Evergreen mixed	*Platycarya strobilacea*
Location	25°19′02″N, 110°15′34″E	25°13′34″N, 110°25′27″E	25°01′40″N, 110°20′23″E	23°13′04″N, 110°23′56″E
Elevation (m)	184–305	166–225	172–211	162–184
Crown density (%)	0.85	0.95	0.75	0.6
Tree height (m)	19	16	17	10
Slope	65–75	40–55	35–45	70–75
Forest age	Near-Mature forest	Near-Mature forest	Near-Mature forest	Near-Mature forest
Soil type	Brown lime soil	Brown lime soil	Brown lime soil	Impure lime soil
Life from	evergreen broad-leaved forest	deciduous and evergreen broad-leaved forest	evergreen broad-leaved forest	deciduous and evergreen broad-leaved forest
Vegetation descriptions	*Cyclobalanopsis glauca* is the monodominant species of trees. The shrubs are sparse, including *Bauhinia championi* and *Millettia pulchra*. The herb layer is discontinuous, including *Ophiopogon bodinieri*	The arbor layer is dominated by *Cyclobalanop–sis* and *Cornus wilsoniana*. The shrubs are sparse, with *Mallotus philippensis* and *Canthium dicoccum*. The herb layer is discontinuous, including *Psychotria prainii* and *Arachniodes exilis*.	There are mainly *Fraxinus griffithii* and *Cyclobalanopsis*. *Fraxinus* is 18-m high, whereas *Cyclobalanopsis* is 16-m high. The shrubs are sparse, including *Vitex negundo* and *Millettia pulchra*. No herbs	*Platycarya strobilacea* is about 10-m high. *Rapanea neriifolia* forms a second layer of trees and is 4–5-m high. The shrubs include *Sageretia thea* and *Millettia pulchra*. The herbs *Carex Linn.* and *Teucrium pernyi* Franch

Determination of maximum water-holding capacity and maximum water-holding rate: All types of litter basically reached saturation after soaking for 24 h; thus, the water-holding capacity at this time was at maximum. Using the mass of litter after soaking for 24 h, the maximum water-holding capacity and maximum water-holding rate were calculated as follows:

$$W_1 = M_{24} - M_0 \quad (5)$$

$$R_1 = (M_{24} - M_0)M_0 \times 100\% \quad (6)$$

where R_0 denotes the natural moisture content of the litter (%); M_1, the mass before drying (g); and M_2, the mass after drying (g).

Determination of the storage capacity and storage rate of litter: The effective interception volume is utilized to estimate the actual interception amount of litter on rainfall using the following formula:

$$W = (0.85R_1 - R_0) \times M \quad (7)$$

where R_0 denotes the natural water content; W, the effective storage capacity ($t{\cdot}hm^{-2}$); 0.85, the effective coefficient; and M, the present amount of litter ($t{\cdot}hm^{-2}$).

Data analysis: Data was analyzed by using Microsoft Excel 2010, and the SPSS software version 23.0 was used for the correlation analysis and significance test of regression equation. The chart was drawn in origin 9.1.

Results

Litters in different forests: The litters produced by different forest types will be influenced by natural factors, such as the proportion of forest components, forest density, growth environment, climate, thickness of the litter itself, and human activities (Li *et al.*, 2018). No significant difference was observed in the amount of litter accumulated in the four planted vegetative forests in Table 2 (p>0.05). The amount of litter accumulated in the *C. glauca* forest was the largest at 8.29 $t{\cdot}hm^{-2}$, followed by the deciduous mixed forest (6.32 $t{\cdot}hm^{-2}$) and then the *P. strobilacea* forest (5.47 $t{\cdot}hm^{-2}$). The amount of litter accumulated in the evergreen mixed forest was the least at 4.64 $t{\cdot}hm^{-2}$.

The undecomposed and semi-decomposed layers of the four forest litters are very significant (p = 0.00). According to the ratio of the four forests with different decomposition levels of the total existing stock, the four types are presented in Fig. 2. The undecomposed layer of forest litter accounted for a larger proportion than the semi-decomposed layer, the undecomposed layer of the *C. glauca* forest and deciduous mixed forest accounted for 60.03% and 59.43%, respectively, whereas the semi-decomposed layer of the deciduous mixed forest and evergreen mixed forest accounted for a larger proportion than the undecomposed layer. This was because the litter in the evergreen mixed forest was difficult to decompose due to slow decomposition rate and had a large accumulation; the litter containing the defoliation component had a faster decomposition rate and less accumulation.

Table 2. Comparison of the amount of litter among the four forests and the composition ratio of the different decomposed layers. The value is expressed as average ± error, and the different letters in the same column indicate significance ($p<0.05$).

Forest type	Total/(t•hm^{-2})	Undecomposed/(t•hm^{-2})	Semi-decomposed/(t•hm^{-2})
Cyclobalanopsis glauca	8.29 ± 1.38a	4.82 ± 0.25a	3.47 ± 0.95a
Deciduous mixed	6.32 ± 0.88ab	3.73 ± 0.27ab	2.59 ± 0.52a
Evergreen mixed	4.64 ± 0.39b	2.74 ± 0.10b	1.91 ± 0.28a
Platycarya strobilacea	5.47 ± 0.36ab	3.18 ± 0.05ab	2.29 ± 0.29a

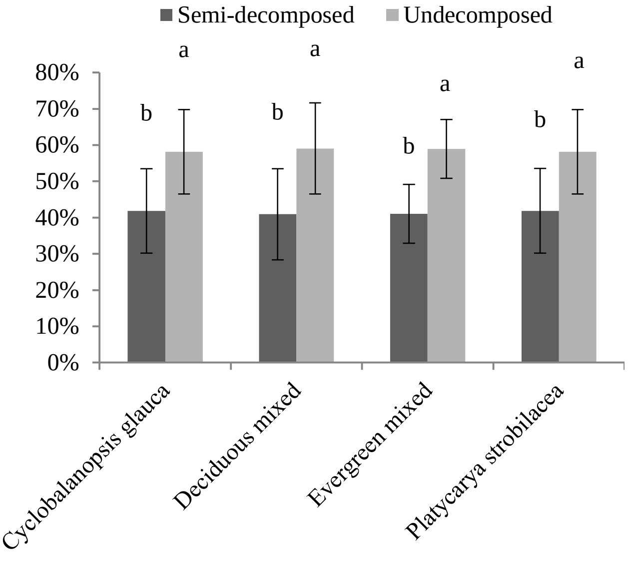

Fig. 2. The proportions of the decomposed layers of the four forest litters in Guilin. The value is expressed as average ± error. Different letters represent significant differences between treatments. The difference between the decomposed layers of the same forest litter is extremely significant ($p<0.00$), and the same decomposed layer of the four forest litters has no significant difference ($p>0.05$).

Water-holding process of litter: When litter enters the water from the air-dried state, its water-holding capacity increase rapidly; The change was the largest within 0–2 h, the increase slowed down after 2 h, and then it tended to a stable saturated state (Fig. 3a). The water-holding capacity of the 4 forest litters was basically the same, whereas the water-holding capacity of the 4 forest litters was quite different. The water-holding capacity of the litters in the *C. glauca* forest and deciduous mixed forest was significantly stronger than that of the litters in the evergreen mixed forest and *P. strobilacea* forest; the water-holding process of the *C. glauca* forest significantly varied. The results showed that in the limestone area, the *C. glauca* forest and deciduous mixed forest had better water-holding capacity. According to the change in the water-holding capacity of the 4 forest litters over time, it was deciduous mixed forest > *C. glauca* forest > evergreen mixed forest > *P. strobilacea* forest, which comprehensively illustrated the litter containing the *C. glauca* component. The water-holding capacity of the stratum changed with time. Such a change was mainly related to the composition and nature of the *C. glauca* forest litter.

The water-holding capacity of each decomposed layer of the four forest litters was the same (Fig. 4). Except for the undecomposed layer of the evergreen mixed forest litter, the water-holding capacity of the undecomposed layer was higher than that of the undecomposed layer. The water-holding capacity of each decomposed layer of the litter significantly varied. The difference in the water-holding capacity between the decomposed layers of the deciduous mixed forest litter was the largest, whereas the difference in the water-holding capacity between the decomposed layers of the *C. glauca* forest litter was relatively small. This indicated that the rate of the litter decomposition and the amount of existing amount had a great influence on the water-holding capacity of the litter.

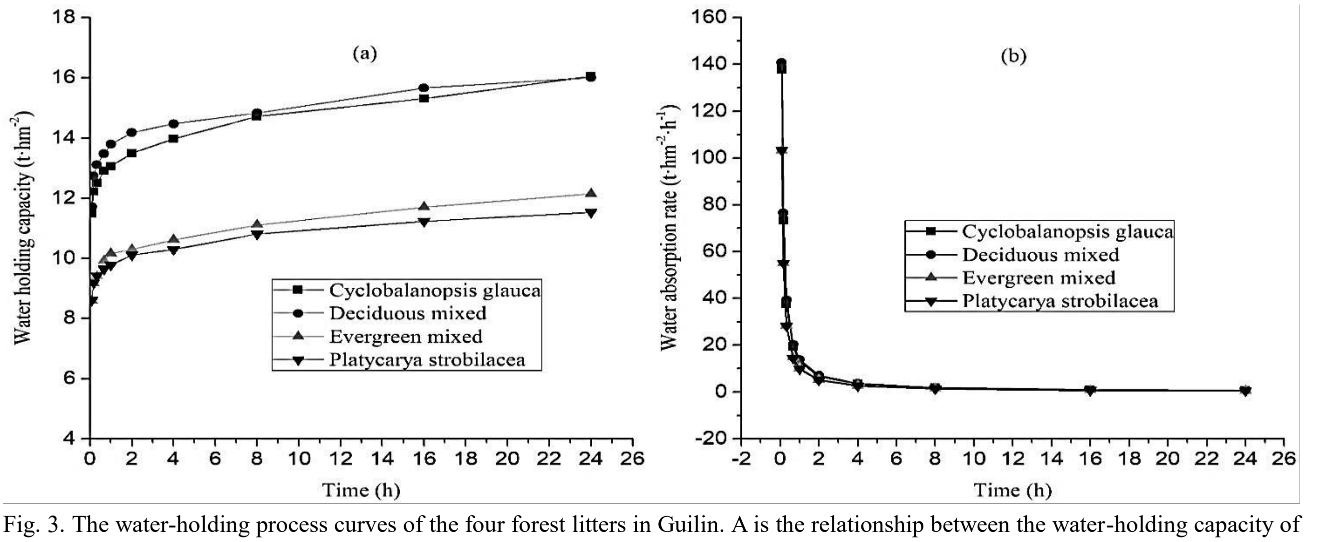

Fig. 3. The water-holding process curves of the four forest litters in Guilin. A is the relationship between the water-holding capacity of the four forest litters over time. B is the relationship between the water absorption rate of the four forest litters over time.

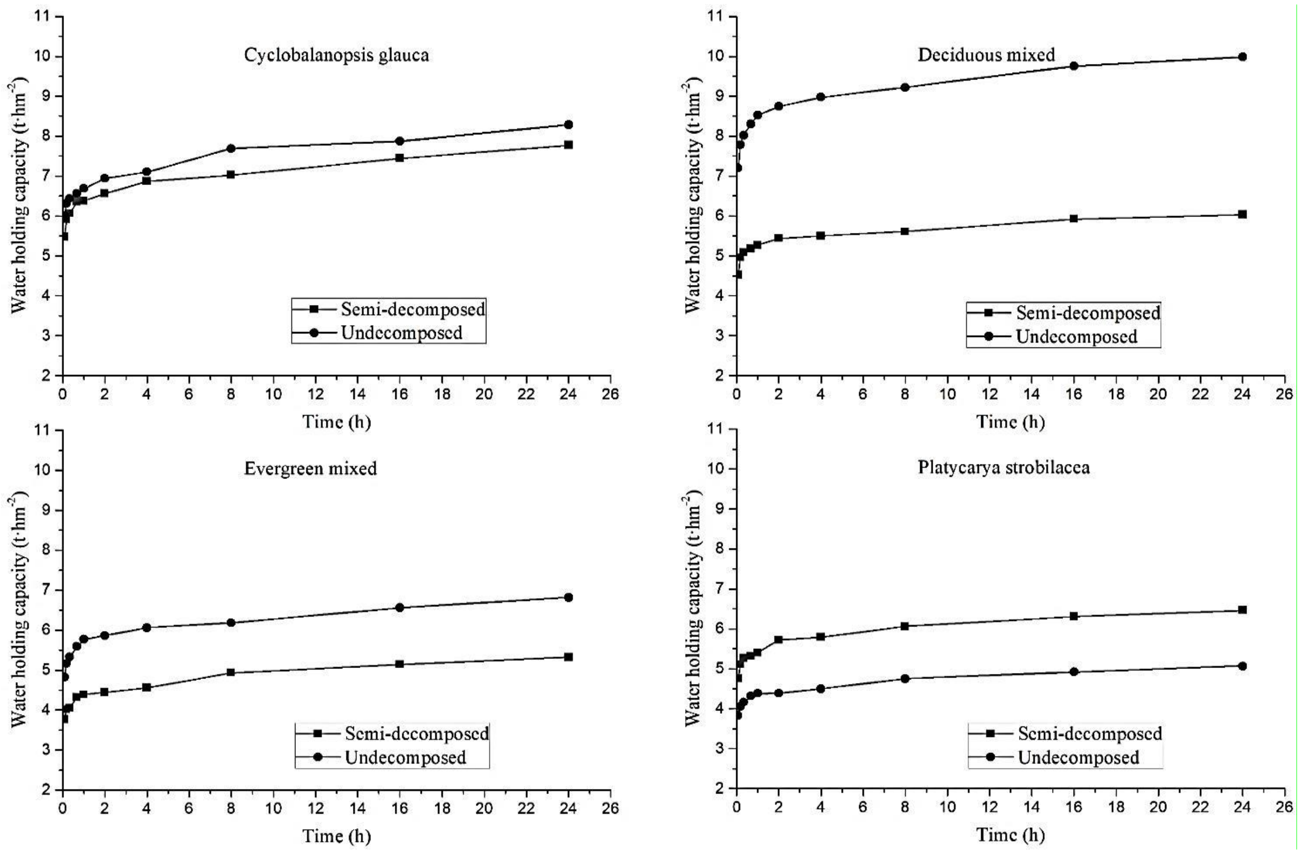

Fig. 4. The water-holding process curves of each decomposed layer of the four forest litters in Guilin. The relationship between the water-holding capacity of the different decomposed layers of the four forest litters over time.

The relationship between the water-holding capacity of each layer of the 4 forest litters and the soaking time was analyzed *via* regression fitting. Such a relationship was a logarithmic function.

$$y = a\ln(t) + b(R^2 > 0.95) \quad (8)$$

where y denotes the water-holding capacity of the litter ($t\cdot hm^{-2}$); t, the soaking time (h); a, the regression coefficient of the equation; and b, the constant term of the equation. The relationship between the water-holding capacity of each decomposed layer of the 4 forest litters and the soaking time is described in Table 2.

Water absorption rate of different forest types: The water absorption rate of the litter of the 4 forest types demonstrated a downward trend with the increase in soaking time. Within 1 h of soaking, the water absorption rate changed the most; within 2–8 h, the water absorption rate of the litter slowly changed; within 8–24 h, the water absorption rate of the litter was basically the same and reached a stable state at 16 h (Fig. 3b). The water absorption rate of the litter of the four types of forest was the largest at the initial stage of soaking. In the first 2 h of soaking, the water absorption rate of the deciduous mixed forest was the largest, and the difference in the water absorption rate between the evergreen mixed forest and *P. strobilacea* forest was not obvious. As time increased, the gap gradually decreased, and finally, the water absorption rate tended to be consistent indicating that the litter had a strong ability of intercepting the initial precipitation, but this ability weakened with time.

The water absorption rate of each decomposed layer of the litter was consistent with the overall change trend. The initial water absorption rate of the undecomposed layer of the deciduous mixed forest litter was significantly greater than that of the semi-decomposed layer (Fig. 5); moreover, the initial water absorption rate of the other three types of litter decomposed layers was not significantly different. The initial water absorption rate of the *P. strobilacea* forest litter of the semi-decomposed layer was greater than the undecomposed layer, and the initial water absorption rate of the other 3 forest litters of the undecomposed layer was greater than the semi-decomposed layer. This indicated that the water absorption rate of the litter was not only influenced by the decomposition speed and existing amount of litter but also by its own biological characteristics.

The relationship between the water absorption rate and the soaking time of each decomposed layer of the four forest litters was analyzed *via* regression fitting, which demonstrated a power function relationship:

$$v = kt^n(R^2 > 0.9994) \quad (9)$$

where v denotes the water absorption rate of the litter ($t\cdot hm^{-2}\cdot h^{-1}$); t, the soaking time (h); k, the coefficient; and n, the index. The relationship between the water absorption rate and soaking time of each decomposed layer of the four forest litters is described in Table 3.

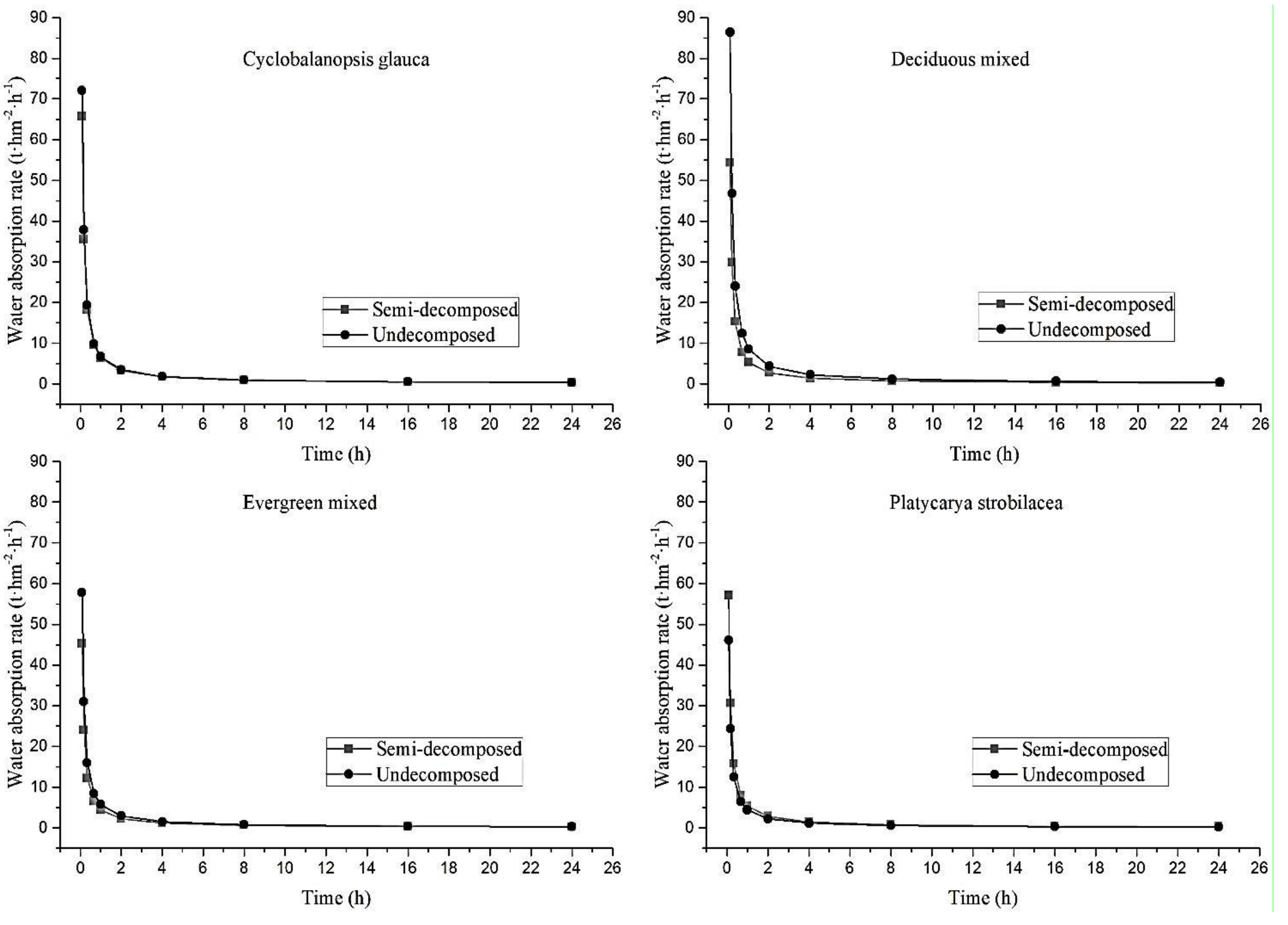

Fig. 5. The water absorption process curve of each decomposed layer of the four forest litters in Guilin. The relationship between the water absorption rate of the different decomposed layers of the four forest litters over time.

Table 3. Relationship between the water-holding capacity and soaking time of litter. Fitting equation parameters of the water-holding rate and water absorption rate of the four forest litters.

Forest type	Layer	Relation	R^2	Relation	R^2
Cyclobalanopsis glauca	Semi-decomposed	y = 3.5985ln (t) + 27.294	0.97464	$v = 26.552t^{-0.872}$	0.9994
	Undecomposed	y = 3.7629ln (t) + 26.256	0.9533	$v = 25.491t^{-0.865}$	0.9996
Deciduous mixed	Semi-decomposed	y = 2.2785ln (t) + 27.552	0.9632	$v = 27.224t^{-0.918}$	0.9995
	Undecomposed	y = 4.4691ln (t) + 42.566	0.986	$v = 41.804t^{-0.897}$	0.9996
Evergreen mixed	Semi-decomposed	y = 2.5576ln (t) + 23.844	0.9674	$v = 23.433t^{-0.897}$	0.9997
	Undecomposed	y = 3.1748ln (t) + 25.808	0.9812	$v = 25.171t^{-0.876}$	0.9995
Platycarya strobilacea	Semi-decomposed	y = 2.7945ln (t) + 28.980	0.9813	$v = 28.561t^{-0.906}$	0.9998
	Undecomposed	y = 1.9574ln (t) + 19.556	0.9685	$v = 19.251t^{-0.903}$	0.9997

Maximum water-holding capacity and maximum water-holding capacity of litter: The water-holding capacity of litter is utilized to reflect the water-holding capacity of litter in Table 4. The maximum water-holding capacities of the 4 forest litters in Guilin were significantly different (p<0.05), which are 11.53–16.05 t·hm^{-2}. The *C. glauca* forest had the highest water-holding capacity, which was 16.05 t·hm^{-2}, followed by the deciduous mixed forest (16.01 t·hm^{-2}) and evergreen mixed forest (12.14 t·hm^{-2}); the *P. strobilacea* forest had the lowest water-holding capacity, which was 11.53 t·hm^{-2}. The maximum water-holding rate variation range of the four forest litters was 202.92%–243.87%, in order of evergreen mixed forest (243.87%) > deciduous mixed forest (243.02%) > *P. strobilacea* forest (230.44%) > *C. glauca* forest (202.92%).

The maximum water-holding capacity and maximum water-holding rate of the semi-decomposed layer of the litter demonstrated opposite changes. The maximum water-holding capacity of the semi-decomposed layer of the *C. glauca* forest litter was the highest, which was 7.77 t·hm^{-2}, and the maximum water-holding rate was the least, which was 213.28%. Contrarily, the maximum water-holding capacity of the semi-decomposed layer of the evergreen mixed forest litter was the least, which was 5.32 t·hm^{-2}, but the maximum water-holding rate was 263.76%. In the undecomposed layer, the maximum water-holding capacity of the deciduous mixed forest litter was the highest, which was 9.98 t·hm^{-2}, as well as its maximum water-holding rate. The *P. strobilacea* forest litter had the least maximum water-holding capacity, which was 5.08 t·hm^{-2}, and its maximum water-holding rate was 209.03%. The maximum water-holding rate of the *C. glauca* forest litter was the least, which was 192.56%, and its maximum water-holding capacity was 8.28 t·hm^{-2}. The maximum water-holding capacity and maximum water-holding rate of the four forest litters had different changing laws, which might be related to the type of vegetation, existing amount of litter, and degree of decomposition.

Storage capacity of different forest types: There were significant differences in the natural moisture content of the 4 forest litters (18.18%–33.64% (p<0.05)); the natural moisture content of deciduous mixed forest was the largest, evergreen mixed forest followed by *C. glauca* forest and *P. strobilacea* forest (Table 5). The difference in the maximum interception rate of litter of 4 forests was extremely significant (p<0.00), at a range of 185.90%–226.64%. The maximum interception rate of the evergreen mixed forest was the largest, followed by deciduous mixed forest and *P. strobilacea* forest, and *C. glauca* forest. Different forest litters had different existing stocks; thus, the effective interception amount and interception depth were also different. The difference between the interception indexes of the four forest litters were extremely significant (p<0.00), which are *C. glauca* forest (127.71 t·hm^{-2}), deciduous mixed forest (114.35 t·hm^{-2}), *P. strobilacea* forest (97.21 t·hm^{-2}), and evergreen mixed forest (86.86 t·hm^{-2}), which were equivalent to intercepting 12.77, 11.44, 9.71, and 8.69 mm rainfall, respectively. Integrating the changing law of the interception capacity of the existing litterfall of the 4 planting types, it could be observed that the *C. glauca* forest had the greatest rainfall interception ability, followed by the deciduous mixed forest and the evergreen mixed forest.

The difference in the natural moisture content of each decomposed layer of the different forest litters was extremely significant (p<0.00), with the semi-decomposed layer having 14.35%–23.86% and the undecomposed layer having 16.14%–26.34%, except for the natural moisture content of the evergreen mixed forest, the semi-decomposed layer is higher than the undecomposed layer, the other three forests have the semi-decomposed layer higher than the undecomposed layer. The maximum interception rate of each decomposed layer of the four forest litters is extremely different (p<0.00); the semi-decomposed layer is larger than the undecomposed layer. The effective interception amount and effective interception depth of both the undecomposed layer was greater than the semi-decomposed layer. According to the changing law of the retention capacity of each decomposed layer of the 4 forest litters, it could be seen that the semi-decomposed layer had the strongest retention capacity, and the actual interception of rainfall was influenced not only by the degree of decomposition of litter but also by other factors.

Table 4. Comparison of the water-holding capacity of the four forest litters, and the difference in the water-holding capacity of each decomposed layer. The value is expressed as average ± error, and the different letters in the same column indicate significance (p<0.05).

Forest type	Maximum water capacity/(t·hm^{-2})			Maximum water-holding capacity/%		
	Semi-decomposed	Undecomposed	Total	Semi-decomposed	Undecomposed	Mean
Cyclobalanopsis glauca	7.77 ± 0.59a	8.28 ± 0.29ab	16.05 ± 0.88a	213.28 ± 4.11c	192.56 ± 2.76d	202.92 ± 3.20c
Deciduous mixed	6.03 ± 0.380a	9.98 ± 0.67a	16.01 ± 0.88a	245.41 ± 2.81b	240.61 ± 5.02a	243.02 ± 2.18a
Evergreen mixed	5.32 ± 0.21a	6.82 ± 0.62bc	12.14 ± 0.63ab	263.76 ± 4.66a	223.97 ± 3.04b	243.87 ± 3.13a
Platycarya strobilacea	6.46 ± 1.89a	5.08 ± 0.33c	11.53 ± 1.97b	251.85 ± 2.81ab	209.03 ± 0.93c	230.44 ± 1.05b

Table 5. Comparison of the differences in the retention and storage energy of the four forest litters, and the difference between the decomposed layers of the litter. The value is expressed as average ± error, and the different letters in the same column indicate significance (p<0.05).

Layer	Forest type	Natural water content/%	Maximum intercept rate/%	Effective interception/t·hm^{-2}	Effective retention depth/mm
Semi-decomposed	*Cyclobalanopsis glauca*	15.98 ± 0.26b	197.30 ± 4.11c	57.36 ± 1.21a	5.74 ± 0.12a
	Deciduous mixed	23.86 ± 2.89a	221.55 ± 2.80b	47.81 ± 0.62b	4.78 ± 0.06b
	Evergreen mixed	17.33 ± 0.64b	256.43 ± 9.88a	39.42 ± 0.75c	3.94 ± 0.08c
	Platycarya strobilacea	14.35 ± 0.29b	237.50 ± 2.81ab	45.78 ± 0.55b	4.58 ± 0.06b
Undecomposed	*Cyclobalanopsis glauca*	16.87 ± 0.32b	174.84 ± 2.49c	70.47 ± 1.02a	7.05 ± 0.10a
	Deciduous mixed	26.36 ± 1.27a	214.26 ± 5.02a	66.50 ± 1.59b	6.65 ± 0.16b
	Evergreen mixed	16.95 ± 0.64b	207.02 ± 3.04a	47.49 ± 0.71d	4.75 ± 0.07d
	Platycarya strobilacea	16.14 ± 0.19b	192.89 ± 0.93b	51.43 ± 0.25c	5.14 ± 0.03c
Total	*Cyclobalanopsis glauca*	20.02 ± 0.75b	186.08 ± 3.04c	127.83 ± 2.04a	12.78 ± 0.20a
	Deciduous mixed	33.63 ± 2.32a	217.91 ± 2.18b	114.31 ± 1.39b	11.43 ± 0.14b
	Evergreen mixed	20.60 ± 0.75b	231.73 ± 6.22a	86.90 ± 1.17d	8.68 ± 0.12d
	Platycarya strobilacea	18.18 ± 0.19b	215.20 ± 1.05b	97.20 ± 0.37c	9.72 ± 0.04c

Discussion

Effect of limestone forest type on litter storage: Li *et al*., (2007) summarized the factors affecting the standing amount of litter into two factors. The first factor refers to the characteristics of the forest itself, mainly including the forest species composition, forest age, density, forest minerals, degree of decomposition, and other internal factors (Sun *et al*., 2018; Wang *et al*., 2020). Generally, with the growth of forest age, the amount of litter in the forest will increase, which is relatively more compact, with smaller pores and larger density (Wang *et al*., 2020). Another factor is the characteristics of the environment, which is categorized into natural environment and human activities. The natural environment mainly includes temperature, humidity, air, and other factors (Zhang *et al*., 2014; Jiang *et al*., 2016; Li *et al*., 2016), whereas human activities mainly refer to a series of effects of human activities on forest production, such as deforestation, air pollution, and man-made afforestation (Yang *et al*., 2016; Zhu *et al*., 2020). The species characteristics of the forest itself influence the quality and quantity of forest litter, and the characteristics of the environment influence the formation and decomposition of the litter layer (Pang *et al*., 2017). Litter accumulation mainly depends on the input of the community to the litter layer, the cumulative years, and the decomposition rate of the litter (Wang *et al*., 2018).

The accumulation of litter in the four forests in the limestone area demonstrates that the *C. glauca* forest, which is a pure forest, is larger than the other three mixed forests. Among the three mixed forests, the litter accumulation of the deciduous mixed forest, which is mainly composed of deciduous components, is significantly higher than that of the normal forest. The evergreen mixed forest, which is mainly green, has a large amount of litter accumulation, which is consistent with the research structure of Li *et al*., (2007) and Cai *et al*., (2021). This is caused by the characteristics of the forest itself. The *C. glauca* forest is a pure forest, and the existing stock is the largest among the four forests. The reason is that its litter composition is more complex than the other three forests. It consists of branches, leaves and fruits, and the fruits have the most difficult-to-decompose husk. The other three mixed forests are litters with a small number of branches. As an evergreen tree of the Fagaceae family, *C. glauca* has a relatively hard structure and strong drought resistance, which is difficult to decompose, this led to a pattern of large differences in the litter stock of different forest types in the same area under the same water and heat conditions. The type of litter has a greater impact on the decomposition rate than the diversity of the litter. Moreover, species diversity promotes the diversity of soil organisms, thereby affecting the decomposition process of the litter (Liu *et al*., 2018c).

The quality of the decomposed layers of the 4 forest litters indicates that the undecomposed layer is more than the semi-decomposed layer, which may be related to the litter sampling season. Plant phenological activities and climate disturbances have different effects on plant biomass and the variability in the formation time of plant litter composition (Zhang *et al*., 2015; Kurihara *et al*., 2018). In different phenological periods, there are significant differences in the ratio of branches, leaves and fruits of litter. In forests where the multiple phenological periods of different canopy plants overlap, the contribution rate of litter may have a seasonal peak (Pang *et al*., 2017). There is a significant difference in the litter stock of the deciduous mixed and evergreen mixed forests. The existing stock of deciduous mixed forests in autumn and winter will be more than that of the evergreen mixed forests (Liu *et al*., 2016; Zheng *et al*., 2020).

However, from the perspective of the quality changes of the semi-decomposed and undecomposed layer, the decomposed layer is basically the same as the overall existing amount. This indicates that under the same climatic and geographical conditions, the decomposition and return of litter of different tree species are greatly influenced by their own biological characteristics. The decomposition rate and turnover of litter increase with the increase in forest tree species diversity. The decomposition rate of litter is affected by its content, for example, the chemical composition and physical structure of litter (Zhang *et al*., 2014; Wang *et al*., 2015). Plant diversity also influences the richness and distribution of microbial communities. By changing the litter composition, litters of different substrate qualities are mixed together, thus providing a diverse habitat for microorganisms, enriching microbial groups, and accelerating litter decomposition (Li *et al*., 2016; Leloup *et al*., 2018). Therefore, the secondary forest has a large amount of litter, high decomposition rate, short turnover period, stable community structure, better nutrient return, and good ability to maintain soil fertility (Liu *et al*., 2016).

The effect of limestone forest type on the litter hydrological effect: Litter is as an important component and functional level of the vertical result of forest ecosystems, litter has good water permeability and water-holding capacity (Li *et al*., 2017; Cai *et al*., 2021). Moreover, it can not only buffer the impact of precipitation but also retain water (Lin *et al*, 2004; Zhang *et al*. 2014), maintain soil erosion, reduce surface runoff, and enhance soil water infiltration (Xuan *et al*., 2018; Du *et al*., 2019; Wang *et al*., 2019). The water-holding process and water absorption rate of forest litter can be divided into three stages. The first is the rapid water absorption stage, which is within 0–2 h at the initial stage of soaking. The second is the slow water absorption stage, which is 2–8 h at the middle stage of immersion. The third is the stagnation and water absorption stage, which is 8–24 h is consistent with the results of others (Chen *et al*., 2017; Pang *et al*., 2017; Du *et al*., 2019). By analyzing the relationship between the water-holding process and soaking time of 4 forest litters, we found that the water-holding capacity of the litter and the immersion time had a logarithmic function relationship ($R^2 > 0.95$, $p = 0.00$) and that the water absorption rate of the litter and the immersion time had a power function relationship ($R^2 > 0.9994$, $p = 0.00$), which was consistent with the research results of others (Li *et al*., 2015; Xuan *et al*., 2018; Tu *et al*., 2019; Zheng *et al*., 2020).

The maximum water-holding rate and maximum retention rate of the semi-decomposed layer of the 4 forest litters in the limestone area of Guilin was greater than the undecomposed layer, and the water absorption rate of the undecomposed layer was greater than that of the semi-decomposed layer in the late soaking stage, which was consistent with the results of Fu *et al*., (2019). The results showed that the water-holding capacity of the semi-decomposed layer of litter reached the saturation point earlier than that of the semi-decomposed layer. For a short-lasting and high-intensity precipitation, the semi-decomposed layer had a stronger water-holding capacity, whereas the undecomposed layer had a longer duration of precipitation. The undecomposed layer could maximize its water-holding capacity only under long-term precipitation. The water conservation capacity of forest litter of the semi-decomposed layer was better than the undecomposed layer, and the composition of forest trees had a great influence on the decomposition rate of litter. The higher the decomposition degree of litter, the stronger will be its water-holding capacity, which is consistent with the findings by Pang *et al*., (2017), Wang *et al*., (2019) and Zheng *et al*., (2020). The water-holding capacity of litter is closely related to the tree species composition, thickness of the litter, and degree of litter decomposition (Lu *et al*., 2019; Huang *et al*., 2020; Wang *et al*., 2020; Zhu *et al*., 2020). The degree of litter decomposition directly determines the water-holding capacity of the litter (Zhang *et al*., 2014).

The water absorption rate, water-holding capacity, and interception capacity of litter are reflected in its absorption capacity, water retention capacity, and interception capacity (Tu *et al*., 2019). The maximum water-holding capacity of the 4 forest litters in the limestone area is in the order of *Cyclobalanopsis glauca* forest > deciduous mixed forest > evergreen mixed forest > *Platycarya strobilacea* forest, and the effective holding capacity is in the order of *Cyclobalanopsis glauca* forest > deciduous mixed forest > *Platycarya strobilacea* forest > evergreen mixed forest. We found that the litter of the *Cyclobalanopsis glauca* forest, a pure forest, in the limestone area had the strongest water conservation capacity, the deciduous mixed forest was stronger than the *Platycarya strobilacea* forest, and the evergreen mixed forest had the weakest interception and soil and water conservation abilities. This was completely contrary to our initial guess. It is not that the more complex the forest combination, the stronger the water conservation capacity of the litter layer. In this study, data on soil hydrological function and forest canopy interception precipitation are lacking. Thus, the results of our research have limitations, but the differences in the hydrological functions of the 4 forest litters in the limestone area of Guilin are found to provide important reference for future research.

Conclusions

Through field investigation and immersion experiments, the hydrological characteristics of the 4 forest litters in the limestone area were analyzed. Combining the changing laws of the litter stock and retention capacity of the four vegetation types, the hydrological function of litter was influenced by the stock, decomposition rate, and biological characteristics of the vegetation itself. It was found that the *C. glauca* forest litter had the largest existing stock, the largest water-holding capacity, and the largest rainfall, indicating that it had a relatively strong hydrological function. Therefore, in areas with similar climates, the *C. glauca* forest can be developed with strong adaptability, excellent materials, and strong water and soil conservation and interception capabilities. The research results provide an important reference for the evaluation of the impact of forest protection and restoration on the soil and water conservation function of the forest ecosystem in the limestone area of Guilin.

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