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Hydrological effects of forest litter and soil in the Simianshan Mountains in Chongqing, China

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Abstract A preliminary study of the hydrological effects of forest litter and soils in the Simianshan Mountains was carried out. Results indicate that the annual accumulation of different forest litters is about 6.80–20.21 t/hm² and the maximum water carrying capacity ranges from 1.8 to 4.6 mm. Among them the water carrying abilities of the litter of *Lithocarpus glabra* and natural deciduous forests are larger than that of *Pinus massoniana*. A power function relationship exists between the accumulated water-carrying volume and time. An investigation of the physical properties shows that forest soils, to a depth of 1 m, have a powerful water-carrying ability, varying from 7.84 to 18.87 mm. Non-linear regression analysis shows that the soil infiltration rate is significantly correlated with time.

Keywords forest litter, forest soil, hydrological effect, Simianshan Mountains

1 Introduction

Forest litter is an important component of forest ecosystems. Litter layers play a crucial role in intercepting and pooling precipitation and function in the process of nutrient circulation and energy transmission in the forest ecosystem. Its ability to intercept water is correlated with its own volume, extent of decomposition, water-carrying capacity as well as litter type (Wu et al., 1992; Cao et al., 1997; Yang and Shi, 1997; Yan et al., 1997). The forest ecosystem in the Simianshan Mountains, near Chongqing City, is a typical subtropical evergreen deciduous forest type in China. Previous investigations in this area mainly focused on the ecological

characteristics of vegetation communities (Yang, 1994; Li, 1995) and species diversity (Zhao et al., 1998; Li, 2000; Wang and Li, 2001), but few hydrological studies are on record. Based on field observations, this study investigated the hydrological effects of forest litter and soils in an effort to provide a theoretical basis for further research on the mechanism of hydrological functions of forest ecosystems.

2 Study area

The Simianshan Mountains are located to the south of Chongqing City (28°31'14"–28°46'00"N, 106°17'22"–106°30'00"E). Its elevation varies from 900 m in the south to 1,500 m in the north. The rock stratum is mainly composed of thick red sandstone of the late Cretaceous Period, which formed the typical Danxia landform under the actions of tensile forces and external agencies. This region has a subtropical monsoon climate with abundant rainfall and a frost-free period of 285 d. The mean annual temperature is 13.7°C with the highest recorded in August at an average of 31.5°C and the lowest temperature in January at an average of –5.5°C. The temperature drops at the rate of 0.58°C for every 100 m increase in elevation. The mean annual precipitation is 1,522.3 mm with a daily maximum up to 160.5 mm. Rainfall is concentrated from May to September, amounting to 62.7% of the yearly total. Precipitation increases by 43.3 mm for every rise of 100 m in elevation. The vegetation, composed of natural secondary forests and plantations, possesses the characteristics of subtropical evergreen deciduous forests. The major timber species are fir (*Cunninghamia lanceolata*), Masson pine (*Pinus massoniana*), cryptomeria (*Cryptomeria fortunei*), stone oak (*Lithocarpus hancei*), myrsinae oak (*Cyclobalanopsis myrsinaefolia*), violet cuckoo (*Rhododendron backii*), Fukien cypress (*Fokienia hodginsii*) and bamboo (*Phyllostachys pubescens*). The soil originates from an acid parent material formed by climate and human activities. The main forest soil types are thick-bone yellow earth, humus yellow earth, mountainous yellow earth in the mountainous region, and cold sand yellow earth.

Translated from *Journal of Beijing Forestry University*, 2005, 27(1): 33–37 [译自: 北京林业大学学报]

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3 Research methods

3.1 Selection and design of standard plots

Standard plots were selected at the following locations in the Simianshan Mountains: Fanjiazhai, Dawopu, Zhangjiashang, Taipingshan, Pizichang and Taiyangping. Standard plots representing different vegetation types were established where we measured tree diameter at breast height (DBH), height, age and the composition of the stands. Five sample plots (50 cm × 50 cm) along the diagonal of the standard plots were selected for litter survey. The results are presented in Table 1.

3.2 Water carrying capacity of forest litter

Given the requirements of the experiment, an original litter sample (50 cm × 50 cm) was collected from each standard plot. Fresh litter weights at the A₀ horizon (non-decomposed) and the A₁ horizon (semi-decomposed) were obtained. After immersion in water for 24 h, they were again weighed. Finally, the litter was dried naturally and their dry weight measured. The water-carrying capacity of various layers could then be calculated.

3.3 Experimental process of water carrying capacity of forest litter

The litter was soaked completely under room temperature of 20°C and its water-carrying capacity measured over several equal intervals.

3.4 Measurement of physical properties and moisture content of soil

Several physical properties such as soil weight, total cavity, non-pipe cavity as well as water content were measured by using the soil box and the circular knife methods.

3.5 Measurement of soil infiltration rate (*K*)

The soil infiltration rate (*K*) was measured by the method of the double-circular ring.

4 Results and analyses

4.1 Analysis of hydrological functions of forest litter

4.1.1 Water carrying capacity analysis

Water-carrying capacity of forest litter can be expressed by using the indicators of maximal water carrying capacity and the maximal water carrying rate of dry mass. This value is correlated with many factors such as forest type, age, composition of forest litter and the condition of its decomposition and accumulation. The maximum water carrying capacity and maximum water carrying rate of litter of the main forest stands in the Simianshan Mountain area are presented in Table 2.

From Table 2 we can see that the maximum water-carrying capacity value of forest litter ranges from 18.24 to 46.37 t/hm², equal to a water depth of 1.8–4.6 mm. The maximum total water-carrying capacity of forest litter of *Lithocarpus hancei*, *Phyllostachys pubescens* and natural deciduous forests are the three highest values and reached 46.37, 40.63, and 37.51 t/hm², respectively. The maximum water-carrying capacity of forest litter of *Cryptomeria fortunei*, *Cunninghamia lanceolata* and *Pinus massoniana* are lower and reached 26.90, 23.13, and 18.24 t/hm², respectively.

The maximum water-carrying capacity of forest litter of mixed plantations of *Pinus massoniana* and *Lithocarpus hancei* and mixed plantations of *Cunninghamia lanceolata* and *Lithocarpus hancei* is higher than that of *Pinus massoniana* and *Cunninghamia lanceolata*. Their values are 24.10 and 34.13 t/hm². The maximum water-carrying rate of forest litter ranges from 284% to 478% and can be recorded in order from high to low as follows: *Cryptomeria fortunei*, mixed plantations of *Cunninghamia lanceolata* and *Lithocarpus hancei*, *Lithocarpus hancei*, mixed plantations of *Pinus massoniana* and *Lithocarpus hancei*, *Pinus massoniana*, *Cunninghamia lanceolata*, *Phyllostachys pubescens*, *Cinnamomum camphora*, and natural deciduous forests.

The water-carrying capacity and the water-carrying rate are not both necessarily at a maximum for the same plantation

Table 1 Basic information of standard plots

Vegetation type	Age /year	Crown density /%	Coverage rate /%	Average height /m	Average DBH /cm	Litter accumulation /(t·hm ⁻²)	Litter depth /cm
Mixed plantation of <i>Pinus massoniana</i> and <i>Lithocarpus hancei</i>	20	78	74	12.2	16.1	17.01	2.5
<i>Lithocarpus hancei</i>	19	66	70	8.2	17.9	13.54	2.8
<i>Pinus massoniana</i>	20	85	75	14.3	14.1	9.12	2.5
<i>Cryptomeria fortunei</i>	20	77	23	10.3	57.7	6.80	3.0
Mixed plantation of <i>Cunninghamia lanceolata</i> and <i>Lithocarpus hancei</i>	20	85	66	11.0	13.0	20.21	2.8
<i>Cunninghamia lanceolata</i>	18	97	40	12.5	11.5	17.05	3.0
<i>Phyllostachys pubescens</i>	25	65	95	11.2	8.1	18.24	3.0
Natural broad-leaved plantation	17	89	87	9.5	7.0	9.12	2.2
<i>Cinnamomum camphora</i>	25	83	93	9.7	15.7	7.31	3.0

Table 2 Maximum litter water carrying capacity of different forest stands

Forest stands	Depth /cm	Accumulation /(t·hm ⁻²)	Maximal water carrying capacity of non-decomposed litters		Maximal water carrying capacity of semi-decomposed litters		Total		Maximal water carrying rate /%		
			/(t·hm ⁻²)	/mm	/(t·hm ⁻²)	/mm	/(t·hm ⁻²)	/mm	Non- decomposed	Semi- decomposed	Total
Mixed plantations of <i>Pinus massoniana</i> and <i>Lithocarpus hancei</i>	3	17.05	10.61	1.1	13.49	1.3	24.10	2.4	321	439	374
<i>Lithocarpus hancei</i>	2.8	13.54	31.95	3.2	14.42	1.4	46.37	4.6	510	358	446
<i>Pinus massoniana</i>	3	6.80	12.03	1.2	6.21	0.6	18.24	1.8	369	350	362
<i>Cryptomeria fortunei</i>	3	7.31	15.81	1.6	11.09	1.1	26.90	2.7	428	584	478
Mixed plantations of <i>Cunninghamia lanceolata</i> and <i>Lithocarpus hancei</i>	2.2	9.12	14.00	1.4	20.13	2.0	34.13	3.4	439	508	477
<i>Cunninghamia lanceolata</i>	2.5	9.12	13.00	1.3	10.13	1.0	23.13	2.3	326	412	357
<i>Phyllostachys pubescens</i>	3	18.24	13.75	1.4	26.88	2.7	40.63	4.1	426	295	326
Natural deciduous forests	2.8	20.21	30.13	3.0	7.38	0.7	37.51	3.7	389	174	284
<i>Cinnamomum camphora</i>	2.5	17.01	25.81	2.6	5.66	0.6	32.10	3.2	389	177	288

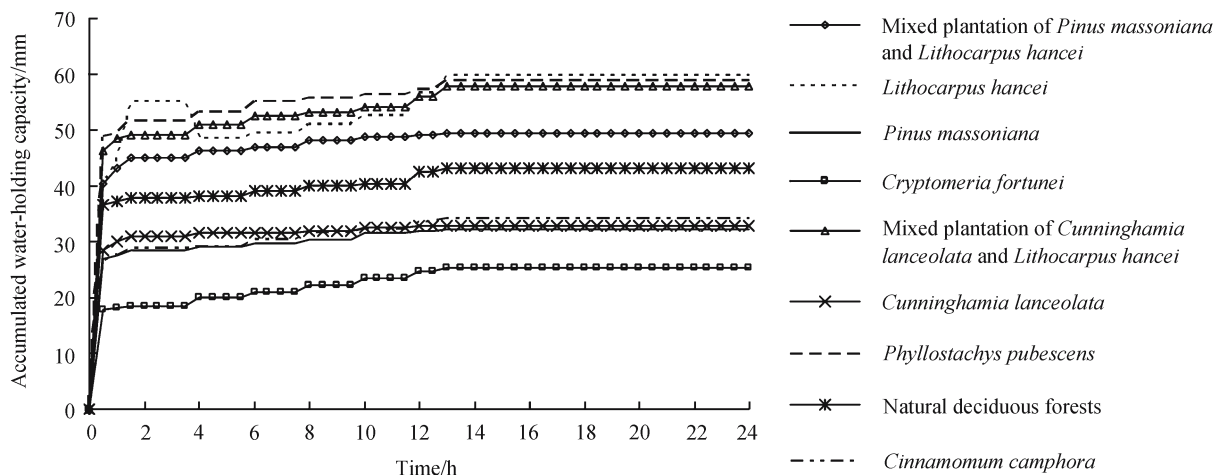
or species, because the maximal water-carrying rate is related to the biomass and structure of the litter itself. In addition, the water-carrying capacity of the litter is affected by the condition of litter decomposition. The more litter is decomposed, the higher its water-carrying capacity. Because of the higher rate of decomposition of the leaves of deciduous trees, its value of water-carrying capacity is higher than that of the litter of coniferous trees.

From this we can see that the water-carrying capacity of non-decomposed litter of deciduous trees is higher than that of conifers. The total water-carrying capacity of the litter of mixed forests is higher than that of pure forests; for example, the total water-carrying capacity of litter of the mixed plantations of *Pinus massoniana* and *Lithocarpus hancei* is 1.32 times larger than that of *Pinus massoniana* and the total capacity of the mixed plantations of *Cunninghamia lanceolata* and *Lithocarpus hancei* is 1.48 times larger than that of *Cunninghamia lanceolata*.

4.1.2 Analysis of the water-carrying process of different forest litters

The rate of water absorption of litter is related to three factors: its moisture condition, litter accumulation and litter structure. The drier the litter is, the faster the rate of water absorption. The water-carrying process of different forest litters has been observed and analyzed by an absorption experiment (Fig. 1). From the results, we can see that the water absorption ability of forest litter rapidly increased half an hour after the start of the experiment. Over time, water absorption increased but at a decreasing rate.

Therefore, we can conclude that the ability of litter to intercept surface run-off is strongest at the start of the water-immersing experiment. As moisture increases, the rate of water absorption ability decreases until the maximum saturation water-carrying ability is reached. These results also indicate that the surface-runoff interception ability of litter is related to its level of moisture content.

**Fig. 1** The water-holding process of different forest litters

We can see from the water-carrying ability curves (Fig. 1) that the litter of *Phyllostachys pubescens* has, after 1/2 h, a maximum water-carrying ability of 48.78 t/hm² and mixed plantations of *Cunninghamia lanceolata* and *Lithocarpus hancei* 46.23 t/hm². *Cryptomeria fortunei* has the least water-carrying ability of 17.68 t/hm². We also see that the water-carrying ability of the litter of deciduous trees is commonly higher than that of conifers after 30 minutes. We carried out regression analyses of the accumulated amount of water absorbed y and the absorption time x (in hours) and obtained the equations displayed in Table 3. From the table, we can see that the correlation coefficients r are, on the average, above 0.89.

Table 3 Regression equations of water carrying amount of different forest litters

Forest type	Regression equation	r	R^2
Mixed plantation of <i>Pinus massoniana</i> and <i>Lithocarpus hancei</i>	$\hat{y} = 40.518x^{0.092}$	0.998	0.996
<i>Lithocarpus hancei</i>	$\hat{y} = 39.192x^{0.162}$	0.956	0.914
<i>Pinus massoniana</i>	$\hat{y} = 26.133x^{0.088}$	0.968	0.937
<i>Cryptomeria fortunei</i>	$\hat{y} = 16.417x^{0.174}$	0.932	0.868
Mixed plantation of <i>Cunninghamia lanceolata</i> and <i>Lithocarpus hancei</i>	$\hat{y} = 45.227x^{0.097}$	0.965	0.932
<i>Cunninghamia lanceolata</i>	$\hat{y} = 28.586x^{0.066}$	0.994	0.989
<i>Phyllostachys pubescens</i>	$\hat{y} = 47.581x^{0.088}$	0.975	0.950
Natural deciduous forests	$\hat{y} = 35.514x^{0.072}$	0.899	0.809
<i>Cinnamomum Camphora</i>	$\hat{y} = 25.708x^{0.116}$	0.966	0.934

4.2 Analysis of hydrological effects of forest land

4.2.1 Physical properties of forest soils and their water carrying ability

Soil bulk density and porosity are two important indicators that reflect the physical property of forest soils. These two indicators are influenced by the growing conditions.

Due to the differences such as the composition of litter, the growing conditions of roots and decomposition, the physical properties of soils differ from each other. Soil non-porosity reflects the soil water-carrying capacity. The physical property and water-carrying ability of four forest soils are presented in Table 4.

We can see from Table 4 that the soil bulk density of farmland is higher than that of forests. Because of cultivation

over long time periods, the soil of farmland has become a compact structure, which does not help in the infiltration of soil water. Soil bulk density of the various forest types are as follows: 1.442 for the mixed conifer and deciduous plantations, 1.306 for mixed deciduous plantations, 1.218 for shrubs and 1.131 for bamboo. There are differences in non-porosity in the soils of different types of vegetation. The non-porosity of deciduous forest soils is higher than that of bamboo and mixed conifer and deciduous plantations. The non-porosity of shrub soils and agricultural land is smaller than the various forest types.

According to the soil water-carrying equation $S = 10,000 hp$ where S is the soil water carrying ability (t/hm²); h is soil depth (m); p is the non-pipe porosity (%).

The average water-carrying capacity in one meter of soil for different types of forest lands is decreasing in the following order: conifer plantations, bamboo, mixed conifer and deciduous plantations, shrubs and farmland. Therefore, the forest soils have an excellent capacity of water conservation; especially the soils of the deciduous forest plantations, which have the highest water-carrying capacity of 188.65 ton per hm² in one meter. This value is 3.1 and 4.7 times that of shrubs and farmland, respectively. The results indicate that deciduous forest plantations are good at improving the physical properties of the soil and strengthening the soil infiltration ability.

4.2.2 Infiltration analysis of forest soils

The property of permeability of forest soils has a direct effect on water movement in the soil. The indicators of permeability of forest soils and farmland are displayed in Table 5.

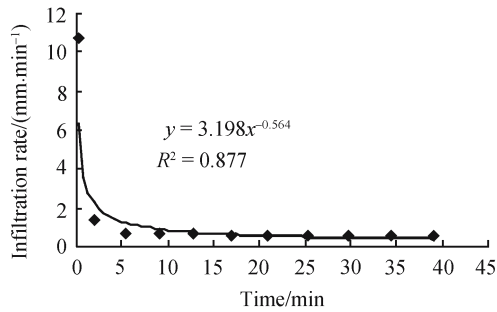
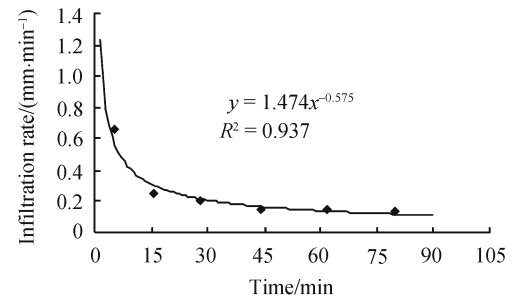
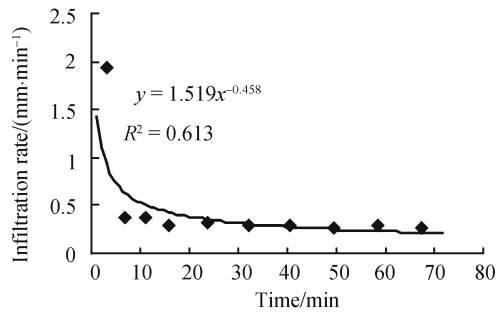
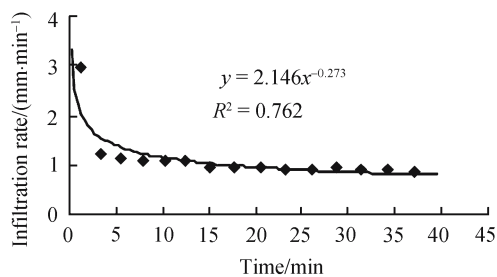
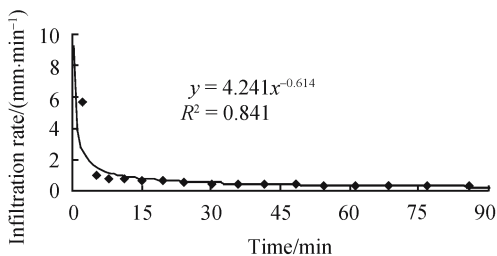
Both original infiltration rate and stable infiltration rate of forest soils are higher than that of farmland. The stable infiltration rate of the various types of soils ranges from 0.28 and 0.52 mm/min. By far, the highest infiltration rate is found in the soil of bamboo forests, followed by that of deciduous plantations. Planted shrubs and mixed conifer and deciduous plantations have similar low rates but are at least twice that of farmland. The many holes made by small mammals in the soil, hidden by bamboo foliage on the ground, benefit the moisture content of the soil for it allows quick water infiltration into the soil; soil osmosis is strong here as opposed to the capillary pores of shrub soils. From the surveys we carried out, we have obtained infiltration curves for soils of the various forest types we encountered in the experiment. These are presented in Figs. 2–6.

Table 4 Physical properties and water carrying ability of different forest soils

Forest type	Soil bulk density (g · cm ⁻³)	Non-pipe porosity /%	Pipe porosity /%	Total porosity /%	Water content rate /%	Water carrying ability in 1 m	
						/(t · hm ⁻²)	/mm
Broad-leaved forests	1.306	18.86	56.42	75.29	55.80	188.65	18.87
Conifer and broad-leaved mixed plantation	1.442	6.93	57.11	64.04	47.29	69.30	6.93
<i>Phyllostachys pubescens</i>	1.131	7.84	66.90	74.74	62.03	78.40	7.84
Shrubs	1.218	6.16	63.85	70.02	63.09	61.65	6.17
Farmland	1.887	3.97	43.12	47.10	24.95	39.75	3.98

Table 5 Soil permeability of different forest soils

Forest type	Soil depth /cm	Soil bulk density /(g·cm ⁻³)	Non-pipe porosity /%	Original infiltration rate /(mm·min ⁻¹)	Stable infiltration rate /(mm·min ⁻¹)	Infiltration coefficient (K) /(mm·min ⁻¹)
Broad-leaf plantation	40	1.306	18.86	10.730	0.521	3.685
Conifer and broad-leaf mixed plantation	73	1.442	6.93	1.940	0.280	1.980
<i>Phyllostachys pubescens</i>	70	1.131	7.84	2.980	0.872	6.167
Shrubs	53	1.218	6.17	5.720	0.295	2.090
Farmland	70	1.887	3.98	0.604	0.138	0.976

**Fig. 2** The broad-leaved forest soil infiltration curves**Fig. 6** The farming land (control) soil infiltration curves**Fig. 3** The coniferous and broad-leaved forest land soil infiltration curves**Fig. 4** The *Phyllostachys pubescens* forest land soil infiltration curves**Fig. 5** The shrub land soil infiltration curves

Water infiltration in agricultural soils is slow compared with that in forest soils. In general, infiltration rates slow down fairly quickly and approach asymptotic values. The various types of forest soils achieve their stable rates at slightly different times. Soils of the bamboo forest reached their stable rate after 37 min, that of deciduous forests after 39 min. The soils of shrubs, mixed conifer and deciduous species and finally farmland reached their infiltration rates, respectively, in 67, 79, and 85 min. In order to analyze the infiltration rates of the various forest soils, we have fitted the following non-linear regression equation of the infiltration rate y (in mm/min) as a function of elapsed time x (in minutes)

$$\hat{y} = ax^{-b}$$

where a and b are constants to be estimated.

Table 6 Regression equations of soil infiltration rates of different forest lands

Forest type	Regression equations	R	R^2
Broad-leaved plantation	$\hat{y} = 3.198x^{-0.564}$	0.936	0.877
Conifer and broad-leaved mixed plantation	$\hat{y} = 1.519x^{-0.458}$	0.783	0.613
<i>Phyllostachys pubescens</i>	$\hat{y} = 2.146x^{-0.273}$	0.873	0.762
Shrubs	$\hat{y} = 4.241x^{-0.614}$	0.917	0.841
Farmland	$\hat{y} = 1.474x^{-0.575}$	0.968	0.937

5 Conclusions and suggestion

1) Litter from the Simianshan Mountain forests has been investigated for its water-carrying capacity. The total

water-carrying capacity ranged between 1.8–4.6 mm. Litter from stone oak forests has the highest capacity with 4.6 mm and 46.37 t/hm² while Masson pine, at 18.24 t/hm², has the smallest water-holding capacity of the forest soils studied.

2) The total water-carrying capacity of litter of the mixed plantations of Masson pine and stone oak is 1.32 times larger than that of Masson pine alone and the total capacity of the mixed fir and stone oak is 1.48 times larger than that of pure fir stands.

3) Forest soils have a strong water-carrying capacity, especially those of deciduous forests, with their capacity 3.1 and 4.7 times as large as that of the soils of shrub and agricultural land. In general, we may conclude that forest soils have a greater water-carrying capacity than agricultural soils.

4) The water infiltration rate of the various soils has been modeled by fitting the non-linear regression function

$$\hat{y} = ax^{-b}$$

which expresses the relationship between infiltration rate and time.

5) The litter of the four types of mountain forests improves the water-carrying capacity of soil layers and ameliorates the protection of the soil in this district. We recommend increased protection by planting deciduous trees and mixed conifer and deciduous stands to enhance the ecological benefits which result in improved water management.

Acknowledgements This paper was supported by the National Natural Science Foundation of China (Grant No. 30500389).

References

- Cao Y C, Zhu L H, Han C S (1997). Hydrological function of forest litters in the eastern mountainous area of Liaoning Province. *J Shenyang Agric Univ*, 28(1): 44–48
- Li X G (1995). Nonlinear ordination of the permanent plots of evergreen broad-leaved forests in the Simian Mountain of Sichuan Province. *Acta Phytocool Sin*, 19(3): 286–292
- Li Y H (2000). Characteristics of species diversity of the secondary shrub in the Simian Mountain at Chongqing. *J Quanzhou Norm Coll (Nat Sci)*, 18(2): 49–53
- Wang J H, Li X G (2001). Chinese study on the interconnections among the main tree population in the evergreen broad-leaved forests in the Simian Mountain of Chongqing city. *J Yuzhou Univ (Nat Sci Ed)*, 3: 58–62
- Wu Q X, Liu X D, Su N H (1992). The stock of the *Populus davidiana* secondary forest litters and its hydrological functions. *J Soil Water Conserv*, 6(1): 71–76
- Yan W D, Zhang X L, Wang J Y (1997). Hydrological functions of forest litters in the Qilian Mountain. *J Northwest For Coll*, 12(2): 7–14
- Yang L W, Shi Q F (1997). Hydrological functions of the main forest litters in the Taihang Mountain. *Chin J For Res*, 10(3): 281–288
- Yang R W (1994). The study on the characteristic of evergreen broad-leaved forests in the Simian Mountain. *J Sichuan Agric Univ*, 12(4): 490–495
- Zhao Q F, Li X G, Liu Y C (1998). A study on the species diversity of the evergreen broad-leaved forests in the Simian Mountain of Chongqing city. *Chin J Southwest China Norm Univ (Nat Sci Ed)*, 23(1): 85–91