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Water-holding characteristics of litter in different forests at the Lianxiahe watershed

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Abstract We surveyed the forest litter amount at the Lianxiahe watershed in the Three Gorges Reservoir Area and analyzed some hydrological characteristics such as the maximum water-holding capacity and water absorption rate of litter in six types of forests, i.e. the *Cupressus funebris* forest, the coniferous mixed forest, the coniferous and broad-leaved mixed forest, the broad-leaved forest, the *Pinus massoniana* forest, the bush forest. Results showed that the litter amount follows the order of the coniferous and broad-leaved mixed forest > the pure *C. funebris* forest, the *P. massoniana* forest > the coniferous mixed forest > the broad-leaved forest > the bush forest. The maximal water holding capacity of the undecomposed litter is in the order of the *C. funebris* forest > the coniferous mixed forest > the bush forest > the coniferous and broad-leaved mixed forest > the broad-leaved forest > the *P. massoniana* forest. The maximal water-holding capacity of the half-decomposed litter is the *P. massoniana* forest > the coniferous and broad-leaved mixed forest > the *C. funebris* forest > the coniferous mixed forest > the broad-leaved forest > the bush forest. In this watershed, the water holding capacity of the litter in the *C. funebris* forest is the highest, followed by the coniferous mixed forest, coniferous and broad-leaved mixed forest, *P. massoniana* forest, broad-leaved forest and bush forest. When the soil is covered only by litter, both the maximal rainfall amount and intensity in different forest stands are different if there is no water infiltration and runoff from the ground surface.

Keywords forest type, litter, water absorption rate, water-holding capacity

1 Introduction

A number of scientists have carried out researches on the litter characteristics of different forest types in different areas, and have made much progress in litter amount, litter dynamic balance, effects of litter on soil structure and mineral cycle, rain water holding, decreasing water evaporation from soil, increasing water infiltration into soil, and effects on runoff and soil erosion (Chen and Xie, 1994; Zhang and Wang, 1997; Zhang et al., 2001; Zhu et al., 2001; Cheng et al., 2002). Ma and Yang (1994) made sure that the litter plays a very important role in rainwater holding. Researches showed that the water-holding capacity of litter depends on its characteristics (Wiersum, 1983; Richard and Granillo, 1985; Dabne, 1998). Wang and Liu (1994) and Wang (2000) studied in detail the relation between litter amount and its water-holding capacity, and the relation among litter water-holding capacity and rainfall, topographic factors in a *Robinia pseudoacacia* stand in the southern Loess Plateau. The study made by Liu and Wu (1991) shows that the relation between the interception of litters in a *Pinus tabulaeformis* stand and the precipitation meets power regression function. Cheng and his colleagues studied litter hydrological characteristics of different forest types in Zigui of Three Gorges Reservoir Area, and their results showed that the hydrological features of litter indifferent forest types is different (Cheng et al., 2003; Zhang et al., 2003).

In order to provide basic data for the building of water protection forest and water and soil conservation forest in the Three Gorges Reservoir Area, in this paper, researches on the litter hydrological features of different forest types were carried out, such as the *Cupressus funebris* forest, the coniferous mixed forest, the coniferous and broad-leaved mixed forest, the broad-leaved forest, the *P. massoniana* forest, and the bush forest.

Translated from *Journal of Huazhong Agricultural University*, 2005, 27(2): 207–212 [译自: 华中农业大学学报, 2005, 24(2): 207–212]

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2 Materials and methods

2.1 The forest stands

The study area is located at the Lianxiahe Watershed in Badong County (30°13'–31°28' N, 110°04'–110°32' E), the branch of Yangtze River in the Three Gorges Reservoir Area. The topography of this watershed is undulant mountainous region with elevation, 800–1,000 m. Continental monsoon climate dominated this area with characteristics of cold and dry in winter, warm and rainy in summer with the annual precipitation about 933.7 mm, the maximum 1,179.7 mm, the minimum 337.0 mm, and annual temperature 17.5°C. The soil is yellow earth. A large area of natural secondary forests exist there, and the main tree species are *C. funebris*, *P. massoniana*, *Quercus* spp., *Ligustrum lucidum*, *Cunninghamia lanceolata*, *Liquidambar formosana*, and there are lots of arbusele species as well which are very important for water and soil conservation in this area.

The typical forest types in this watershed and their basic information were described in Table 1.

2.2 Materials

The typical forest types in this area were plotted for our research including the coniferous and broad-leaved mixed forest, the pure *C. funebris* forest, the *P. massoniana* forest, the coniferous mixed forest, the broad-leaved forest and the bush forest (referred as the capital letter A to F in Table 1). Original state litter of different forest types were collected as experiment materials.

2.3 Methods

2.3.1 Litter collection

In each typical forest a plot was built with the size of 10 m×10 m or 10 m×20 m and repeated for 2–3 times according to the stand situation. In each typical forest plot, three

small plots were set as well for litter collection with the size of 20 cm×25 cm at upper, middle and down slope. Before collecting litter, we separated them into undecomposed and half-decomposed litter layer, then surveyed the layers' thickness, and at last put them into different boxes. The litter's in undecomposed layer keeps its original morphological state of branches and leaves, and the litter in half-decomposed layer still keeps its original morphological state of branches and leaves and can be recognized with eyes, but it has been decayed to a certain degree.

2.3.2 Water-holding capacity and water absorption rate of litter

1) Litter amount: litter were weighed in the unite of t/hm² after drying naturally.

2) Litter water-holding characteristics: weighed litter were put into the soil sieve in its original state and were soaked in water, and then were took out from water to weigh every 30 min placing for 5 min until no water drop. After two hours later, the wet weight of litter was weighed every two hours with the same above method till 20 hours. In this way, the water-holding capacity and water absorption rate can be calculated from the difference of the dry and the wet litter weight, and the unit of water-holding amount should be exchanged into unit of mm according to the area of litter plot.

With these data, we can also find the relationship between the water-holding amount and the soaking time, then test the regression with 95% or 99% confidence level.

3 Results and analyses

3.1 Litter amount of different forest types

The litter collected from plots was put on dry place over 1 week, and its weight was recorded after feeling no moisture when touching. The results are presented in Table 2.

Table 1 The basic information of different forest types in the study area

Forest type	Elevation /m	Slope /(°)	Aspect	Canopy density	Forest age	Average height /m	DBH average /cm
<i>Cupressus funebris</i> forest (A)	910–920	35	North	0.66	Middle age	9.53	13.37
Mixed coniferous forest (B)	880–920	28	East	0.50	Young	6.80	8.05
Coniferous and broad-leaved mixed forest (C)	880–900	25	East	0.67	Middle age	13.73	16.93
Broad-leaved forest (D)	870–900	25	East	0.83	Middle age	10.80	12.57
<i>Pinus massoniana</i> forest (E)	810–820	34	North	0.71	Middle age	15.40	17.20
Bush forest (F)	780	24	North	0.72			

Table 2 Litter amount of different forest types

Forest types	Total quantity (t·hm ⁻²)	Undecomposed litter		Half-decomposed litter	
		Quantity	Percentage /%	Quantity	Percentage /%
A	19.36	7.78	40.19	11.58	59.81
B	16.35	6.07	37.13	10.28	62.87
C	21.90	5.74	26.21	16.16	73.79
D	11.48	4.74	41.29	6.74	58.71
E	18.87	5.35	28.35	13.52	71.64
F	10.52	5.91	56.18	4.61	43.82

From Table 2 we can find that there is a difference in the litter amount in 6 forest types, the maximum litter amount is in the coniferous and broad-leaved mixed forest, the second is in the pure forest of *C. funebris*, the third is in the forest of *P. massoniana*, the coniferous mixed forest and the broad-leaved forest, and the minimum is in the bush forest in quantity order. The experiment shows as well that the percentage of litter in half decomposed layer comparing to that in undecomposed layer is more than 50% for all forest types except for the bush forest, the biggest one is that of the coniferous and broad-leaved mixed forest, the second the forest of *P. massoniana*, and the least the bush forest. This is because litter of coniferous forest is hard to decompose and in half decomposed state, and the bush forest is consisted of broadleaf trees with little leaf and is decomposed easily.

3.2 The effect of decomposing degree on its water holding characteristics

The water holding quantities for both half decomposed and undecomposed litter in different forest types is shown in Table 3. From Table 3 we can find that the water holding quantity for undecomposed litter layer in the *C. funebris* forest is the highest, the coniferous mixed forest the second, the bush forest the third, and the *P. massoniana* forest the least. We can also find that the water holding quantity for half decomposed litter layer in the *P. massoniana* forests the highest, the coniferous and broad-leaved mixed forest the second, the *C. funebris* forest the third and the bush forest the least.

With the data of the maximal water holding of half decomposed and undecomposed litter layer, we can find that the maximal water holding of half decomposed litter layer for all forest types is more than that of undecomposed litter

layer except for the coniferous mixed forest and the bush forest.

We can also find that the total water holding of litter in the *C. funebris* forest is the highest, and in the coniferous mixed forest and the coniferous and broad-leaved mixed forest are the second, which means litter in the *C. funebris* forest, the coniferous mixed forest and the coniferous and broad-leaved mixed forest have very strong ability of water holding in Lianxiahe watershed, and has lesser ability in the bush forest. We can also find from the Tables 2 and 3 that there is obvious difference in the litter amount and its water holding per area among the different forest types.

We find from Table 3 as well that both the weight and the maximal water holding per area of undecomposed litter in the coniferous mixed forest are the highest, and those in the bush forest follow next, in the broad-leaved forest, the *C. funebris* forest and the coniferous mixed forest follow next in order, and those in the *P. massoniana* forest are the least. In contrast to undecomposed litter layer, both the weight and the maximal water holding per area of half decomposed litter in the bush forest are the highest, those in the broad-leaved forest, the *C. funebris* forest and the coniferous mixed forest follow the next in order, and those in the coniferous and broad-leaved mixed forest are the least. The maximal water holding per area of undecomposed litter in the coniferous mixed forest is 0.17 mm/(t·hm²), and it is equal to that in the *P. massoniana* forest. Both the weight and the maximal water holding per area of total litter in the bush forest are the highest, in the coniferous mixed forest, the *C. funebris* forest and the broad-leaved forest follow the next in order, and in the *P. massoniana* forest and the coniferous and broad-leaved mixed forest are the least. That means litter layer for water holding in the bush forest is very high, in the *C. funebris* forest and in the broad-leaved forest follow the next, and in the *P. massoniana* forest is the least.

Table 3 Maximal water holding of unit area and unit weight litter in different forest types

Forest types	Undecomposed litter			Half-decomposed litter			Total quantity		
	MHW	ALF	MHWU	MHW	ALF	MHWU	MHW	ALF	MHWU
A	1.98	7.78	0.25	2.21	11.58	0.19	4.19	19.36	0.22
B	1.83	6.07	0.30	1.76	10.28	0.17	3.59	16.35	0.22
C	1.27	5.74	0.22	2.28	16.16	0.14	3.55	21.90	0.18
D	1.21	4.74	0.26	1.49	6.74	0.22	2.70	11.48	0.24
E	1.10	5.35	0.21	2.30	13.52	0.17	3.40	18.87	0.18
F	1.57	5.91	0.27	1.09	4.61	0.24	2.66	10.52	0.25

MHW: Maximal water holding/mm; ALF: Quantity of litter (t/hm²);
MHWU: Maximal water holding of unit (mm/(t·hm²))

3.3 The relation between the water holding and the immersion time of litter

3.3.1 The relation between the water holding quantity and the immersion time for litter

The logarithmic regression relation between the water holding quantity and the immersion time of litter has been obtained by some researches, and we obtained the basically same result (see Figs. 1 and 2 and Table 4). We can find from Figs. 1 and 2 that the water holding quantity for litter varies rapidly with the immersion time in the first 8 hours, but it varies less afterwards, so we take the water holding quantity of litter of immersion 20 hours as the maximal water holding.

3.3.2 The relation between the water absorption rate and the immersion time of litter

The relation between the water absorption rate and the immersion time for litter meets power regression (see Figs. 3 and 4 and Table 5). Figures 3 and 4 show that the water absorption rate for undecomposed litter varies rapidly with the immersion time in the first 6 hours, but it varies less

afterwards. In contrast to undecomposed litter, half decomposed litter varies rapidly with the immersion time in the first 8 hours, but it varies less afterwards, especially for the *C. funebris* forest, the mixed coniferous forest, the broad-leaved forest, the *P. massoniana* forest and the bush forest. The forest type regression curves of half decomposed litter water absorption rate to the immersion time almost overlap. This result means that the effect of forest type on water absorption rate is very little. However, the regression curve of the water absorption rate of half decomposed litter in the coniferous and broad-leaved mixed forest is far away from those in other forest types, because the water absorption rate of both half decomposed and undecomposed litter in the coniferous mixed forest are much bigger than those in other forest types, which may be concluded to the litter chemical difference.

3.4 The relation between the water holding quantity of the litter layer and rainfall

The maximal water holding of the litter layer for the *C. funebris* forest, the coniferous mixed forest, the broad-leaved forest, the *P. massoniana* forest, and the bush forest are

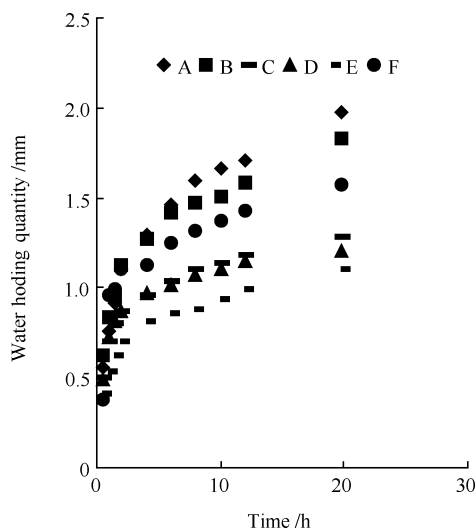


Fig. 1 Relation between the water holding of the undecomposed litter and immersion time

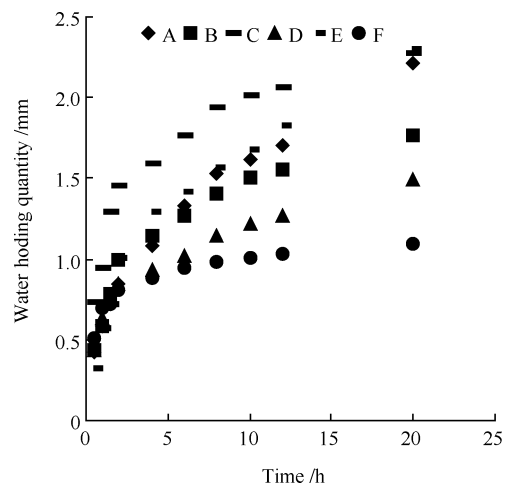


Fig. 2 Relation between the water holding of the half-decomposed litter and immersion time

Table 4 The relation between the water holding quantity and the immersion time of litter ($t < 20$ h)

Forest types	Undecomposed litter		Half-decomposed litter	
	Regression	R^2	Regression	R^2
A	$S=0.382,8\ln t+0.789,3$	0.995,2**	$S=0.466\ln t+0.579,4$	0.959,9**
B	$S=0.307,8\ln t+0.850,1$	0.989,9**	$S=0.363,5\ln t+0.655,3$	0.991,1**
C	$S=0.199\ln t+0.689,5$	0.988,6**	$S=0.417,9\ln t+1.046,1$	0.986,2**
D	$S=0.180,5\ln t+0.701,3$	0.968,6**	$S=0.263,2\ln t+0.621,1$	0.978,3**
E	$S=0.177,7\ln t+0.547,1$	0.991,3**	$S=0.508,3\ln t+0.587,6$	0.978,9**
F	$S=0.262\ln t+0.798,8$	0.890,1*	$S=0.149,4\ln t+0.666,2$	0.978,7**

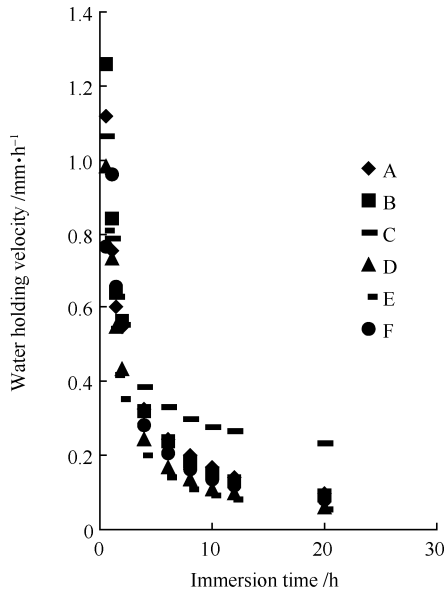


Fig. 3 Relation between the water holding velocity of the undecomposed litter and immersion time

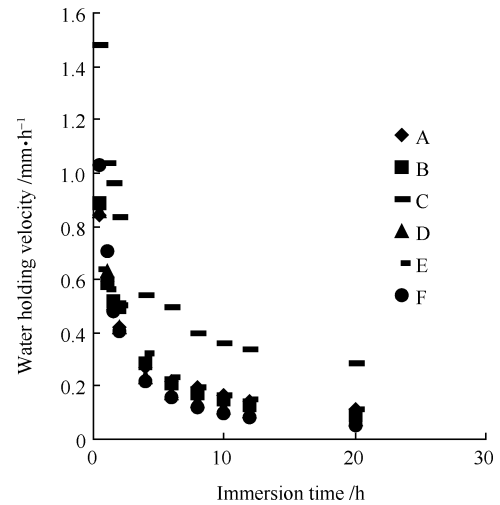


Fig. 4 Relation between the water holding velocity of the half-decomposed litter and immersion time

Table 5 The relation between the water holding velocity and the immersion time for litter ($t < 20$ h)

Forest types	Undecomposed litter		Half-decomposed litter	
	Regression	R^2	Regression	R^2
A	$V=0.775,5t^{-0.664,5}$	0.993,9**	$V=0.593,1t^{-0.558,3}$	0.998,2**
B	$V=0.841,1t^{-0.730,7}$	0.995,6**	$V=0.640,3t^{-0.629}$	0.986,7**
C	$V=0.754,8t^{-0.427}$	0.987,9**	$V=1.088t^{-0.462,7}$	0.992,4**
D	$V=0.686,3t^{-0.785,7}$	0.992,0**	$V=0.613,4t^{-0.696,4}$	0.992,5**
E	$V=0.539,4t^{-0.75}$	0.996,0**	$V=0.564,3t^{-0.502,3}$	0.958,4**
F	$V=0.738,6t^{-0.712,1}$	0.946,8**	$V=0.660,2t^{-0.812,5}$	0.996,7**

4.19, 3.59, 3.55, 2.70, 3.40, and 2.66 mm respectively. The maximal water absorption rate of the litter in the *C. funebris* forest, the coniferous mixed forest, the broad-leaved forest, the *P. massoniana* forest, and the bush forest are 1.960, 2.149, 2.541, 1.839, 1.451, and 1.794 mm/h respectively. When rainfall intensity is less than water absorption rate of litter in a stand, all rainfall can be absorbed by litter layer. For example, when rainfall is less than 4.19 mm and rainfall intensity less than 1.96 mm/h in the *C. funebris* stand, all rainfall can be absorbed by litter layer and no erosion appears. So are the other forest types.

4 Discussion

There is difference in the litter amount of six forest types and the ratio of undecomposed to half composed litter, which is due to the different tree component and decomposing speed in 6 forest types. Water holding capacity of litter in coniferous stand is better than that in broadleaved stand. The water holding quantity of litter varies rapidly in six forest types in the first 4 hours, then it varies less, gets

saturation after 8 hours and keeps steadiness. So, the effect of litter in different forest types on water holding is very little.

Because of rainfall being absorbed by litter as the first step in a stand, the rest of the rainwater reaches the soil after saturation for the litter layer. If the rainfall in a stand is less than the water holding quantity and the rainfall intensity is less than the water absorption rate of litter, no rainwater infiltrates to soil and no erosion happens.

We have studied the differences of litter amount, the water holding quantity and water absorption rate of litter in 6 forest types in this paper. We would like to carry out a research program on dynamic balance of litter in different seasons and the effect of dynamic balance of litter on soil characteristics and the rainfall distribution in a forest system in the very near future.

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