Water Holding Characteristics of Litters from Different Ecological Public Welfare Forest Types

Rui Shi[1], Biao Li[2], Shaoxiong Liu[3] and Shu Wang[1, *]

[1]College of Landscape Architecture, Southwest Forestry University, Kunming, PR China

[2]Key Laboratory of the Ministry of Education for Agro-Biodiversity and Pest Management, Yunnan Agricultural University, Kunming, PR China

[3]Kunming Edible Fungi Institute of All China Federation of Supply and Marketing Cooporatives, Kunming Yunnan, PR China

*Corresponding author

Abstract—**Water holding characteristics, including, water holding capacity, water holding rate and absorption rate, together with the litter stock from five public welfare forests with different tree composition and identity were measured. The purpose was to understand water-conserving functions of the three plantations. The results showed that litters from five public welfare forests have different characteristics. The great litter production of litter in different ecological public welfare forest types was of *Pinus yunnanensis* forest, followed by the litter of *Alnus nepalensis* forest, *Cunninghamia lanceolata* forest, *Eucalyptus globulus* forest, and the least amount of litter stock was from *Quercus variabilis* forest. The total water holding capacity and water holding rate of litter increased logarithmically with increasing immersing time, according with logarithmic equation $W=a*\ln(t)+b$. Water absorption rates of litter in all plantations decreased according to power correlation with increasing time immersed in water, it accord with power equation $W=a*t^{-b}$ ($P < 0.001$).**

Keywords-ecological public welfare forest; litter; water holding capacity; water holding rate; water absorption rate

I. INTRODUCTION

The ecological public welfare forests have multiple functions, including water and soil resource conservation, biodiversity protection, disaster prevention, nutrient and energy balance maintenance [1]. Forest litter has been defined as the organic matters that ultimately returned to the soil surface. Forest litter plays a significant role in promoting the circulation of substances, nutrient balance and maintaining the functions of the forest ecosystem [2-4]. So for, papers of forest litter were about litter decomposition, relation of forest litter and soil nutrient, dynamic model based on forest litter and N, C cycle, effect of forest litter to hydrology, function of forest litter to ecosystem, allelopathic effects of leaf litters, and so on. Litter decomposition rate is strongly affected by nutrient content, water-soluble carbon compound and structural carbon compound in early decomposition period, whereas it is mainly controlled by lignin and cellulose/lignin ratio in later decomposition period. Soil animal can break litter, soil microorganism is an important factor for litter decomposition and human activities also have influence in the litter decomposition [5]. Decomposition rates of forest litter are significantly influenced by climate and fauna along an elevation gradient [6-7], and the climatic variability across an elevation gradient may be the strongest determinant of decomposition dynamics [8]. The most relevant studies have analyzed changes in decomposition rates of native litter types across climatic gradients [7, 9-12]. Fragmentation was shown to be a major process contributing to the stabilization of litters derived C and N in soil organic matter [13]. The hydrologic cycle of forest litter was affected by the weight of the litter, the shape of the leaf litter and rainfall intensity [14]. Forest litter layer can absorb water, and increase roughness of the earth's surface so that retard surface runoff, enhance moisture permeability [18]. The porous of litter are larger than soil, so litter can promote water infiltration, delaying time of runoff, lighten erosion degree of runoff, and supply enough water to soil and plants [19]. Some papers show that the capacity of water conservation of litters in different standing forest is diversity [20-24]. This paper investigated litter in five public welfare forest and researched water holding characteristics of litter with the purpose of understanding water conservation function of litters, and this paper can supply scientific proof to development of public welfare forest in Yunnan, China.

II. THE GENERAL SITUATION OF SAMPLING SITE

The sampling sites are located in Mengzi county of Yunnan, China, a subtropical climate with temperate and rainy area. The sample plots were karst landform, the soil was acid red soil with thick soil layer, fertile and damp soil. The original vegetation was *Alnus nepalensis* natural pure forest, Present vegetation landscape showed complex and mosaic distribution patterns with natural secondary forest and planted forest. This study analyzed water holding characteristic of litter in *Alnus nepalensis* natural pure forest, *Pinus yunnanensis* planted forest, *Cunninghamia lanceolata* natural secondary forest, *Quercus variabilis* natural secondary forest and *Eucalyptus globulus* planted forest. The stand characteristics of experimental field were shown by table 1.

TABLE I. THE STAND CHARACTERISTICS OF EXPERIMENTAL FIELD

Types of forest	Canopy density	Average height of threes /m	Average diameter at breast height /cm	Density /plants·hm^{-2}
Alnus nepalensis natural pure forest	0.91	23.42	26.18	1826
Pinus yunnanensis planted forest	0.87	19.35	20.84	2172
Cunninghamia lanceolata natural secondary forest	0.85	21.05	24.69	1460
Quercus variabilis natural secondary forest	0.76	7.44	11.83	6015
Eucalyptus globulus planted forest	0.92	24.91	17.32	2634

III. METHOD OF RESEARCH

The sample area (400 m^2 of five different ecological public welfare forests, respectively) was researched in April, 2011, with 3 repetitions. The stockage, water holding capacity, water holding rate and water absorption rate of litters collected from five different public welfare forests were measured experimentally. For each sample area, five quadrat samples of the size of 1 m×1 m were used for measurements. Collected fresh litter from five different public welfare forests were weighted, and their litter moisture content were measured. The litter of each quadrat samples was immersed for 0.5, 1.0, 1.5, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 16.0 and 20.0 hours, then those were weighed after picked up and drain for five minutes. The water holding, water holding rate and water absorption rate of litter were calculated according to follow formulas [25-26]:

Water holding capacity (kg·m^{-2}) = Quality of fresh litter (kg·m^{-2}) - Quality of dry litter (kg·m^{-2})

$$\text{Water holding rate (\%)} = \frac{\text{Water holding capacity}}{\text{Quality of dry litter}} \times 100\%$$

$$\text{Water absorption rates (g·kg}^{-1}\text{·h}^{-1}) = \frac{\text{Water holding capacity}}{\text{Immersed time}} \times 100\%$$

IV. RESULTS AND ANALYSES

A. Litter Production and Moisture of Litter

The litter production of litter from five public welfare forests was different, as shown in table 2. The largest stockage of litter was from *Pinus yunnanensis* planted forest, which was 2.36 kg·m^{-2}. One possible reason was that high content of fibre in pine needle so that it is difficult to be digested by microorganism. The second largest stockage of litter was from *Alnus nepalensis* natural pure forest, (2.06 kg·m^{-2}), whereas the least stockage of litter was from *Quercus variabilis* natural secondary forest, (1.63 kg·m^{-2}). *Quercus variabilis* are deciduous trees, -and it is likely that the litters from last winter have been digested by microbial action -so that there were few new litters left. Interestingly, *Alnus nepalensis* are deciduous trees as well, but their litter stock was higher than that of *Quercus variabilis*, one possible reason was that *Alnus nepalensis* densities were very high, contributing to high levels of litter input. Because *Alnus nepalensis* grows on moist slop land and ravine, this might explain why the largest moisture content of litter was found in *Alnus nepalensis* natural pure forest. By contrast, litters from evergreen coniferous species, *Pinus yunnanensis* and *Cunninghamia lanceolata* had small capillary interstice and high moisture-holding capacity, and thus their moisture content was relatively lower compared to *Alnus nepalensis* natural pure forest.

TABLE II. THE STOCKAGE OF LITTER IN FIVE DIFFERENT PUBLIC WELFARE FORESTS

Types of forest	Quality of fresh litter(kg·m^{-2})	Quality of dry litter(kg·m^{-2})	Moisture content of litter (%)
Alnus nepalensis natural pure forest	3.68	2.06	44.02
Pinus yunnanensis planted forest	2.97	2.36	20.54
Cunninghamia lanceolata natural secondary forest	2.65	2.00	24.53
Quercus variabilis natural secondary forest	2.01	1.63	18.91
Eucalyptus globulus planted forest	2.23	1.88	15.60

B. The Relationship between Water Holding Capacity and Immersed Time

The Fig.1 shown that the water holding capacity of litters from five public welfare forests were different, revealed water holding capacity of litters were related to quality of litters and immersed time. In same immersed time, the order of water holding capacity of litters was: litters in *Alnus nepalensis* natural pure forest > litters in *Pinus yunnanensis* planted forest > litters in *Quercus variabilis* natural secondary forest > litters in *Cunninghamia lanceolata* natural secondary forest > *Eucalyptus globulus* planted forest. The water holding capacity of litters generally increased with increasing immersed time. The water holding capacity increased hastily with immersing process during the a half hour to eight hours, and then increased slowly during eight hours to twelve hours, and rarely changed after being immersed for twelve hours. After immersed for twenty hours, the water holding capacity of litters in *Alnus nepalensis* natural pure forest, *Pinus yunnanensis* planted forest, *Quercus variabilis* natural secondary forest, *Cunninghamia lanceolata* natural secondary forest and *Eucalyptus globulus* planted forest were 6.5, 6.1, 5.8, 5.6 and 4.8 kg·m^{-2}.
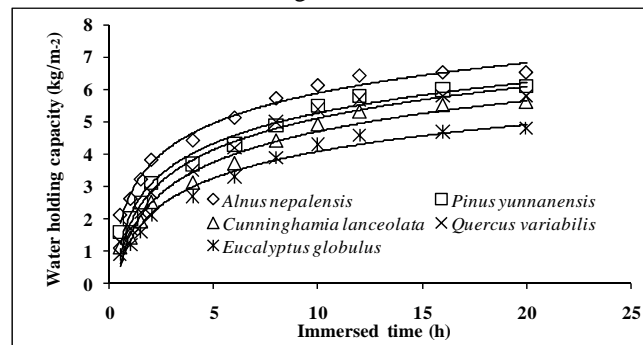

FIGURE I. THE RELATIONSHIP BETWEEN WATER HOLDING CAPACITY AND IMMERSED TIME

The water holding capacity of litters increased with increasing time immersed in water, according with logarithmic equation W_H=a*ln (t) +b (table 3). The related coefficient of theoretical water holding capacity of litters base on W_H=a*ln(t)+b with the measured water holding capacity were greater than 0.98, P < 0.001, revealing that water holding capacity was significantly related with immersed time.

TABLE III. THE EQUATION OF WATER HOLDING CAPACITY WITH IMMERSED TIME

Types of forest	Equations	Related coefficient	P
Alnus nepalensis natural pure forest	W_H=1.3338ln(t) + 2.797	0.9835	<0.001
Pinus yunnanensis planted forest	W_H = 1.3491ln(t) + 2.1471	0.9876	<0.001
Cunninghamia lanceolata natural secondary forest	W_H = 1.3645ln(t) + 1.57	0.9901	<0.001
Quercus variabilis natural secondary forest	W_H = 1.4028ln(t) + 1.8771	0.9842	<0.001
Eucalyptus globulus planted forest	W_H = 1.1961ln(t) + 1.3364	0.9915	<0.001

C. The Relationship between Water Holding Rate and Immersed Time

The water holding rate of litter is a very important aspect of moisture holding capacity, high water holding rate revealed strong moisture holding capacity. The Fig.2 showed that the water holding rates of litters were also related to quality of litters and immersed time. In same immersed time, the order of water holding rate of litters was litters in *Alnus nepalensis* natural pure forest > litters in *Quercus variabilis* natural secondary forest > litters in *Pinus yunnanensis* planted forest>litters in *Cunninghamia lanceolata* natural secondary forest > *Eucalyptus globulus* planted forest. The order of water holding rate of litters was different from the order of water holding capacity of litters. Water holding rate of litters from deciduous forest was higher than evergreen forest, evergreen coniferous forest was higher than evergreen broad-leaved forest. The water holding rate of litters increased with increasing immersed time. And the water holding rate and increased hastily with prolonging immersing time during half an hour to ten hours, and increased slowly during ten hours to twelve hours, but hardly changed after twelve hours, it explaining water holding rate of litter verge to saturation after immersed for twelve hours. The water holding rate of litter from *Alnus nepalensis*, *Quercus variabilis*, *Pinus yunnanensis*, *Cunninghamia lanceolata* and *Eucalyptus globules* were 315.53%, 355.83%, 254.79%, 278.61% and 255.32%, revealed *Alnus nepalensis* and *Quercus variabilis* can be reproducing tree species of forest for conservation of water supply.
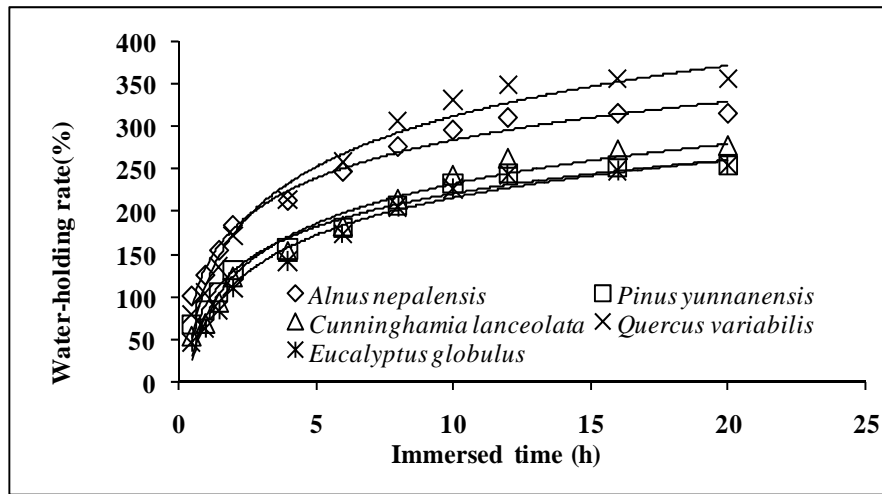

FIGURE II. THE RELATIONSHIP BETWEEN WATER HOLDING RATE AND IMMERSED TIME

The water holding rate of litters increased with increasing time immersed in water, according with logarithmic equation W_R=a*ln(t)+b, it was shown by table 4. The related coefficient of theoretical water holding rate of litters base on W_R=a*ln(t)+b with the measured value were greater than 0.97, P < 0.001, revealing that water holding rate was significantly related to immersed time.

TABLE IV. THE EQUATION OF WATER HOLDING RATE WITH IMMERSED TIME

Types of forest	Equations	Related coefficient	P
Alnus nepalensis natural pure forest	W_R = 64.749ln(t) + 135.78	0.9842	<0.001
Pinus yunnanensis planted forest	W_R = 56.787ln(t) + 91.206	0.9788	<0.001
Cunninghamia lanceolata natural secondary forest	W_R = 67.751ln(t) + 78.013	0.9746	<0.001
Quercus variabilis natural secondary forest	W_R= 86.061ln(t) + 115.16	0.9762	<0.001
Eucalyptus globulus planted forest	W_R = 63.623ln(t) + 71.083	0.9771	<0.001

D. The Relationship between Water Absorption Rate and Immersed Time

Both Water holding capacity and water holding rate of litter increased with prolonging time of immersing, On the contrary, water absorption rate decreased with prolonging time of immersing as shown by Fig.3. The water absorption rate decreased hastily with prolonging time of immersing among half hour to six hours, but decreased slowly after immersed for six. Therefore, the function of regulating water resources of litter in public welfare forest was most prominent for six hours after rainfall. In same time, the order of water holding rate of litters was litters in *Alnus nepalensis* natural pure forest > litters in *Pinus yunnanensis* planted forest > litters in *Quercus variabilis* natural secondary forest > litters in *Cunninghamia lanceolata* natural secondary forest > *Eucalyptus globulus* planted forest. The water absorption rate of litter from *Alnus nepalensis*, *Quercus variabilis*, *Pinus yunnanensis*, *Cunninghamia lanceolata* and *Eucalyptus globules* were 4200, 3200, 2600, 2200 and 1800 $g \cdot kg^{-1} \cdot h^{-1}$, revealed water absorption rate of litter in five public welfare forest were different.
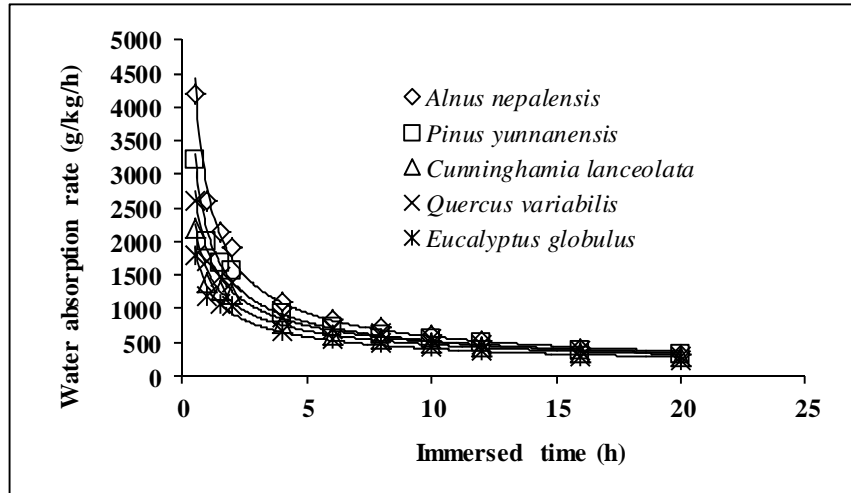

FIGURE III. THE RELATIONSHIP BETWEEN WATER ABSORPTION RATE AND IMMERSED TIME

The water absorption rate of litters decreased with increasing time immersed, it accord with power equation $W_A = a \cdot t^{-b}$, it was shown by table 5. The related coefficient of theoretical water absorption rate of litters base on $W_A = a \cdot t^{-b}$ with the measured value were greater than 0.98, $P < 0.001$, revealed water absorption rate significantly related with immersed time.

TABLE V. THE EQUATION OF WATER HOLDING RATE WITH IMMERSED TIME

Types of forest	Equations	Related coefficient	P
Alnus nepalensis natural pure forest	$W_A = 2771.1t^{-0.677}$	0.9945	<0.001
Pinus yunnanensis planted forest	$W_A = 2151t^{-0.617}$	0.9938	<0.001
Cunninghamia lanceolata natural secondary forest	$W_A = 1568.8t^{-0.53}$	0.9861	<0.001
Quercus variabilis natural secondary forest	$W_A = 1856.5t^{-0.566}$	0.9855	<0.001
Eucalyptus globulus planted forest	$W_A = 1327.9t^{-0.518}$	0.9815	<0.001

V. CONCLUSION

(1) The production of litters from five public welfare forests were different, reserves of litters in Pinus yunnanensis planted forest were largest, that were 2.36 kg·m-2, then were from Alnus nepalensis natural pure forest, Cunninghamia lanceolata natural secondary forest and Eucalyptus globulus planted forest, and Quercus variabilis natural secondary forest were least.

(2) The water moisture content of litters in five public welfare forests were very different, the largest were Alnus nepalensis natural pure forest, and were 44.02%. The second large were evergreen coniferous forest, water moisture content of litters in Pinus yunnanensis planted forest and Cunninghamia lanceolata natural secondary forest were 20.54% and 24.53%. Water moisture content of litters in Eucalyptus globulus planted forest and Quercus variabilis natural secondary forest were 18.91% and 15.60%.

(3) The water holding capacity and water holding rate of litters increasing with immersed time. Water holding capacity and water holding rate increased hastily with prolonging immersing time during half an hour to eight hours, and increased slowly during eight hours to twelve hours, but hardly changed after twelve hours. The water holding rate of broad leaved deciduous forest were largest, the second were evergreen coniferous forest, the least were broad-leaved evergreen forests.

(4) The relationship of water holding capacity or water holding rate with immersed time were accord with logarithmic equation that was W=a*ln(t)+b, in which a and b were constant, the relationship between water absorption rate with immersed time were accord with power equation that was W=a*t-b. Those two equations could use to imitate reality change of water holding capacity, water holding rate and water absorption rate of litter in different public welfare forest, this result was similar with previous research results [21, 27].

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