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Original Research Paper

Hydrological Effects of Forest Litter and Soil on Different Density Plantations of *Pinus sylvestris* L. Var. *mongolica* Litv. in Mu Us Sandland, Northwest China

Ruiping Hou*, Kebin Zhang*†, Bilal Ahmad*(**), Lili Wang* and Xiao Wang*
*School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
**Department of Forestry and Range Management, PMAS-UAA, Rawalpindi, Pakistan
†Corresponding Author: Kebin Zhang

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ABSTRACT

A pilot study of hydrological effects of litter and soil layers was carried out on different density plantations of *Pinus sylvestris* L. Var. *mongolica* Litv. in the southeast of Mu Us Sandland. For the purpose of evaluating the hydrological function of litter and soil quantitatively, 30 standard plots (10 types of forest×3 replications) were investigated. The soil physical characteristics and water-holding capacity were determined. The results showed that: (1) The total storage capacity of litter among 10 forest types, generally followed by the sequence of forest densities, were $P_{III} = P_{IV} > P_X > P_{VII} > P_{IX} > P_{VI} > P_{VII} > P_V > P_{II} > P_I$; the maximum water-holding capacity and effective water-holding capacity of litter, for 10 forest types, were 2.46-8.23 t/hm^2 and 0.163-6.42 t/hm^2, respectively. (2) There were no significant differences in water content, bulk density and the maximum water-holding capacity of soil amongst these forest types, with the variation range of 8.94-16.54%, 1.10-1.66 g/cm^3 and 200.43-266.43 t/hm^2, respectively. However, the non-pore porosity of soil among these 10 forest types varied greatly with a variation range of 0.99-4.32%. The hydrological effects of soil were the highest in the P_{III} and P_{IV} plots, and the lowest in the P_I plot. (3) The power function model can better indicate high correlation coefficients between the water absorption rate of litter and its immersion time, and also between the water-holding capacity of litter and its soaking time. The stable infiltration rates of soil in 10 different forest stands were consistent, while they varied greatly with a range of 0.11-0.89 mm/min after 20 minutes. (4) In this study, the hydrological effects of forest litter and soil in P_{III} and P_{IV} plots were the best, and the optimal afforestation density was 1500 to 1800 plants per hectare. The results show that thinning should be done timely and appropriately in this study area to prevent the recession of a forest stand. Besides, it is unapproachable whether *Pinus sylvestris* Var. *mongolica* can be planted in large scale or in high density, and further research is needed.

INTRODUCTION

Forest ecosystem is composed of trees, shrubs, forest litter and soil. The unique aspects of forest structure, forest litter and soil have great influence on the forest ecological functions of water conservation. However, there are certain differences in the water conservation functions of forest due to different biological characteristics, varieties of stand structures and forest types (Wu 2006, Zhou & Yu 2003). In recent years, scholars have mainly focused on the research of the litter storage capacity, litter decomposition rate, soil structure, rainfall interception and soil infiltration characteristics of different regions while few research studies were conducted on *Pinus sylvestris* L. var. *mongolica* Litv. in artificial forest land, especially in arid or semi-arid areas (Zhang et al. 2002, Yan et al. 1997, Geng & Wang 2000, Tian et al. 2005, Liu et al. 2001, Chen et al. 2006). For example, Liu et al. (1991) found that the litter thickness of *Pinus tabuliformis* forests was negatively related to the soil evaporation in the semi-arid Loess Plateau region of China, and the water content of soil could be efficiently improved by increasing the thickness of litter. Yin & Liang (2007) indicated that the age of artificial forests of *Hippophae rhamnoides* Linn. was negatively related to the storage capacity and water-holding rate of the litter in Erdos city, inner Mongolia. These storage capacity and water-holding capacity, associated with site conditions and stand age, were the main factors affecting the litter water-holding capacity. Other related studies on the litter storage capacity, the water-holding capacity and the process of the main forest types in Liupan Mountains, Ningxia Hui autonomous region in China, showed that the litter storage capacity of coniferous forest was the highest, followed closely by the broadleaf forest, and that of the shrub was the lowest. The evaporation rate of litter layer increased like an S-shape curve with the increase of litter water content (Shi et al. 2009).

China is affected by sandstorm severely. Various techniques and researches have been applied to deal with the problems of desertification. *Pinus sylvestris* L. var.

mongolica Litv. is a geographic variation species of pines in the far east, native to Hulunbeier District in Da-Hinggan mountains (Meng et al. 1991). It is an important afforestation species, with the obvious functions of water and soil conservation, windbreak and sand-fixation in the north of China. It has been widely used in the construction of shelter belt. The growth characteristics and physiology of *Pinus sylvestris* var. *mongolica* have been well studied in arid regions (Wang et al. 1999, Zhao et al. 1991, Wu et al. 2003), but quantitative research on the hydrological effects of forest litter and soil on different density plantations of *Pinus sylvestris* var. *mongolica* in sandy land is still lacking.

A case study was conducted in Yulin city, Shaanxi Province, northwest China. Taking the artificial forest of *Pinus sylvestris* var. *mongolica* as an example, the primary objective of this study was to analyse and compare the hydrological effects of forest litter and soil on 10 different density plantations, aimed to reveal the hydrological conservation function of *Pinus sylvestris* var. *mongolica.* This recent study results will provide useful information for supporting the management of forest ecosystems, afforestation, combating desertification and promoting water use efficiency in future.

OVERVIEW OF THE STUDY AREA

The study site is located at the Yulin Research Station of State Forestry Administration, which lies in the north of Shaanxi Province and the southern edge of Mu Us Sandland, China. The geographical coordinates are 109°42'54" E and N 38°20'11" with an altitude of 1250 m above sea level. It lies in the semi-arid temperate continental monsoon climate region. The annual average temperature is 8.8° and the frost-free period ranges from 134 to 153 days. The annual average precipitation is 358.1 mm. The soil type is the fixed aeolian sandy soil. The main plant species include *Pinus sylvestris* L. var. *mongolica* Litv., *Pinus tabuliformis, Salix matsudana* Koidz, *Robinia pseudoacacia* L., *Populus euphratica* Oliv., *Salix psammophila, Juniperus sabina* Linn., *Hedysarum scoparium, Hedysarum mongolicum* Turcz., *Lespedeza davurica, Medicago sativa, Artemisia desterorum* Spreng and *Setaria viridis.*

Table 1: Stand structure characteristics of the sample plots.

Plot number	Canopy density (%) (plant/hm^2)	Planting density	Average DBH (cm)	Average H(cm)	Ratio of H/DBH breath(m)	Average crown
P_{I}	30±6	900±27	19.04±3.29	12.06±2.13	0.63±0.043	4.06±1.23
P_{II}	45±8	1200±35	13.00±1.24	9.89±1.25	0.76±0.012	3.12±2.45
P_{III}	47±3	1500±46	16.67±1.23	13.26±1.23	0.79±0.032	4.19±2.42
P_{IV}	46±4	1800±34	12.10±2.31	12.08±2.32	0.95±0.021	3.28±2.31
P_{V}	56±2	2200±42	12.29±4.32	11.79±2.34	0.95±0.035	1.99±3.21
P_{VI}	53±6	2500±36	13.18±3.45	8.30±2.12	0.62±0.042	2.68±1.24
P_{VII}	60±5	2800±48	15.17±1.34	10.16±3.21	0.66±0.032	4.07±2.34
P_{VIII}	73±2	3000±37	11.65±1.11	11.00±1.23	0.94±0.011	2.01±1.24
P_{IX}	78±4	3300±46	12.65 ±1.23	8.35±3.21	0.66±0.023	2.50±2.34
P_{X}	85±6	3600±57	11.51±1.43	7.62±3.45	0.66±0.031	2.49±2.35

± represents standard deviation, same as in other Tables.

Table 2: Litter storage capacity under different afforestation densities.

Plot Number	Non-decomposed (L layer)				Half-decomposed (L layer)			
	Thickness		Storage capacity		Thickness		Storage capacity	
	(cm)	(%)	(t/hm^2)	(%)	(cm)	(%)	(t/hm^2)	(%)
P_{I}	1.23±0.11	47.85±4.56	1.21±0.12	47.83±3.45	1.34±0.12	52.14±4.56	1.32±0.12	52.17±3.43
P_{II}	1.32±0.12	48.00±5.32	1.32±0.12	48.00±4.54	1.43±0.13	52.00±3.43	1.43±0.14	52.00±3.20
P_{III}	3.21±0.12	49.30±4.67	3.24±0.32	49.32±3.21	3.30±0.32	50.69±3.21	3.33±0.13	50.68±2.34
P_{IV}	3.40±0.13	48.85±4.32	3.25±0.32	49.47±2.12	3.56±0.42	51.14±4.56	3.32±0.16	50.53±3.12
P_{V}	1.52±0.14	49.35±4.76	1.65±0.24	48.53±2.12	1.56±0.32	50.64±5.64	1.75±0.32	51.47±3.21
P_{VI}	1.64±0.23	49.54±5.78	2.32±0.12	48.64±2.34	1.67±0.11	50.45±4.21	2.45±0.36	51.36±3.12
P_{VII}	2.34±0.23	48.85±5.31	2.13±0.21	47.54±2.13	2.45±0.21	51.14±4.65	2.35±0.21	52.46±4.56
P_{VIII}	2.31±0.24	48.73±3.45	2.56±0.12	49.04±2.13	2.43±0.32	51.26±5.32	2.66±0.43	50.96±5.32
P_{IX}	1.42±0.14	49.47±4.21	2.34±0.42	45.88±2.12	1.45±0.43	50.52±4.21	2.76±0.54	54.12±4.31
P_{X}	1.52±0.16	49.83±4.56	2.54±0.42	46.95±2.32	1.53±0.55	50.16±4.31	2.87±0.43	53.05±4.21

MATERIALS AND METHODS

Sample plot selection: The artificial forests of *Pinus sylvestris* var. *mongolica* were planted in the 1980s, and the age of the stands was 30 years. All stands lie above the same sea level where the water table is low, for which the underground water was buried deeply in a forest stand, and the soil water from precipitation influx is the main source to the vegetation. The volume of soil water depends on the vegetation type in the area. Ten sample plots (with the plot size of 20m × 20m) with three replications (total 30 plots) were selected on the basis of different densities ranges i.e., from 900 to 3600 plants per hectare. After the plantation, there was little human disturbance within the forest, and these plants were ensured to grow in their natural habitat.

Field investigation and lab determination: The present status of the study area was investigated extensively based on field inventory. All the study parameters such as crown density, number of trees, diameter at breast height (DBH), height (H) and crown cover were measured and recorded. Table 1 shows that the ratio of H to DBH of P_{III} and P_{IV} sample plots are the highest amongst these 10 forest types with better forest structure.

Six quadrats (with the size of 1.0m × 1.0m) were randomly selected in each sample plot, and then the half-decomposed and non-decomposed litter, in every quadrat, was collected and the litter thickness was measured simultaneously. The decomposed litter was attributed to the half-decomposed one as it was not distinguishable (Zhang et al. 2003). After classification, the collected litter was taken to the lab, and was weighed before oven-drying at 102°C to a stable weight.

In addition to the above parameters, soil profile was hand-dug and ten soil layers were divided. The ten soil layers were: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, 70-80 cm, 80-90 cm and 90-100 cm. In each unit, three replications were collected. And then these samples were taken back to the lab, where the water content, the bulk density and porosity of soil were determined respectively by the method of drying and using the cutting ring. The method of double loop osmosis was used to determine the soil permeability (Bai et al. 2009).

Data Processing

***Calculation of the water-holding capacity and water absorption rate*:** The water-holding capacity and water absorption rate of the litter were measured by soaking method:

$$\Delta W_{ij} = (W_{i(j+k)} - W_{ij}) \;/\; W_{(j+k)-j}$$

Where, ΔW_{ij} is the water content of the i^{th} litter layer from time j to time $j+k$ (g/kg); W_{ij}, $W_{i(j+k)}$ are the wet weights of the i^{th} litter layer at time j and time $j+k$ (g); $W_{(j+k)-j}$ is the wet weight of the i^{th} litter layer from time j to time $j+k$ (kg).

The water absorption rate of litter measurement is as follows (Deng et al. 2014):

$$\Delta S_{ij} = \Delta W_{ij} \;/\; \Delta t_{ij}$$

Where, ΔS_{ij} is the water absorption rate of the i^{th} litter from time j to time $j+1$ (g/(kg·h)); Δt_{ij} is the time interval from time j to time $j+1$ (h).

***Calculation of the effective interception capability*:** The effective interception capability of litter is calculated as follows (Jiang et al. 2007):

$$W = (0.85Rm - Ro)M$$

Where, W is the effective interception capability of litter (t/hm^2); R_m is the maximum water-holding rate (%); Ro is the average water content ratio (%); M is the litter storage capacity (t/hm^2).

***Determination of the soil water-holding capacity*:** The soil water-holding capacity is calculated by using the formula,

$$S = 1000ky$$

Where, S is the soil water-holding capacity (t/hm^2); k is the soil thickness (cm); y is the soil non-pore porosity (%).

RESULTS AND ANALYSIS

Comparison and analysis of the litter storage capacity of 10 forest types: The litter storage capacity is influenced by stand age, forest type, stand structure, human activities, decomposition rate and thickness of litter etc. (Lin et al. 2002). Table 2 shows that the thickness and storage capacity of half-decomposed and non-decomposed litter account for about 50% of the total respectively among all plots. However, the highest thickness of the half-decomposed was found in P_{IV} plot, followed by P_{III} plot closely, while the lowest thickness of the half-decomposed appeared in P_I plot. The thickness and storage capacity of half-decomposed litter were slightly higher than those of non-decomposed litter, which were consistent in all plots. The litter total storage capacity of all sample plots was in the following order: $P_{III} = P_{IV} > P_x > P_{VII} > P_{Ix} > P_{VI} > P_{VII} > P_V > P_{II} > P_I$.

Comparison and Analysis of Litter Water-Holding Function of 10 Forest Types

***The influence of afforestation density on litter water-holding capacity*:** From data analysed above, the litter thickness and storage capacity in P_{III} and P_{IV} plots were higher than the others. In order to test its actual interception ability, the water-holding capacity of litter was calculated. It can be seen clearly from Table 3 that the litter water-holding func-

Table 3: Litter water-holding capacity under different afforestation densities.

Plot Nomber	Litter layer	Water content (t/hm^2)	Maximum water holding rate(%)	Maximum water holding capacity (t/hm^2)	Effective water holding rate(%)	Effective water holding capacity (t/hm^2)	Effective intereception capacity (t/hm^2)	Water content rate(%)
P_I	L layer	0.12±0.012	121±32	1.23±0.11	90±11	0.12±0.012	1.21±0.11	11±2
	F layer	0.098±0.0023	100±44	1.23±0.21	98±12	0.043±0.0034	1.02±0.21	12±1
P_{II}	L layer	1.21±0.031	121±11	1.02±00.14	100±21	1.11±0.12	1.11±0.13	21±3
	F layer	1.12±0.12	143±21	2.00±0.13	120±21	1.32±0.11	1.02±0.20	15±4
P_{III}	L layer	3.21±0.32	100±14	4.32±0.15	154±13	3.21±0.10	3.21±0.34	44±5
	F layer	2.98±0.45	154±15	3.43±0.42	132±14	3.21±0.23	2.89±0.32	33±1
P_{IV}	L layer	3.43±0.24	142±21	4.56±0.22	161±15	3.65±0.22	3.32±0.43	37±3
	F layer	2.87±0.42	137±21	3.67±0.21	154±16	2.65±0.23	2.13±0.21	21±5
P_V	L layer	1.34±0.21	100±16	2.12±0.20	110±11	1.23±0.33	1.54±0.25	14±2
	F layer	1.58±0.32	104±17	1.45±0.23	114±10	1.34±0.21	1.32±0.26	15±1
P_{VI}	L layer	1.54±0.21	105±14	2.34±0.33	118±21	1.45±0.14	1.32±0.23	17±1
	F layer	1.64±0.32	128±12	2.54±0.21	124±13	1.54±0.15	1.20±0.32	13±1
P_{VII}	L layer	1.78±0.34	126±13	2.43±0.21	92±14	1.66±0.23	1.43±0.24	21±4
	F layer	1.54±0.32	125±12	2.00±0.11	93±12	1.60±0.33	1.32±0.24	22±2
P_{VIII}	L layer	2.42±0.45	110±12	2.54±0.10	120±15	1.34±0.12	1.54±0.50	15±2
	F layer	2.56±3.21	121±11	1.78±0.23	121±16	2.31±0.21	1.32±0.44	18±2
P_{IX}	L layer	1.79±0.21	110±25	2.56±0.34	132±19	2.54±0.32	2.13±0.32	24±1
	F layer	2.54±0.45	121±20	2.04±0.44	110±21	1.45±021	1.45±0.15	21±4
P_X	L layer	2.21±0.32	116±10	2.21±0.32	116±11	2.33±0.23	2.15±0.31	23±3
	F layer	2.31±0.65	100±11	1.99±0.12	114±15	1.45±0.21	1.89±0.31	26±2

Table 4: The relationship between water-holding capacity of litter and its soaking time.

Plot Number	Non-decomposed (L layer)		Half-decomposed (F layer)	
	Equation	Correlation coefficient (R^2)	Equation	Correlation coefficient (R^2)
P_I	y=421.26ln(x)+1425.30	0.928	y=229.09ln(x)+2341.60	0.784
P_{II}	y=404.51ln(x)+1739.10	0.931	y=214.83ln(x)+388.08	0.832
P_{III}	y=311.49ln(x)+1016.40	0.853	y=158.74ln(x)+3089.80	0.732
P_{IV}	y=228.29ln(x)+828.22	0.855	y=312.17ln(x)+367.20	0.897
P_V	y=134.70ln(x)+1530.50	0.915	y=275.53ln(x)+3111.50	0.752
P_{VI}	y=350.60ln(x)+949.38	0.966	y=187.08ln(x)+3465.80	0.861
P_{VII}	y=155.96ln(x)+1254.90	0.942	y=250.82ln(x)+199.83	0.732
P_{VIII}	y=160.33ln(x)+1216.40	0.971	y=208.99ln(x)+329.10	0.654
P_{IX}	y=67.88ln(x)+945.55	0.912	y=216.94ln(x)+1084.20	0.741
P_X	y=363.64ln(x)+1519.20	0.964	y=36.94ln(x)+1129.60	0.815

Table 5: The relationship between water absorption rate and immersion time of litter.

Plot Number	Non-decomposed (L layer)		Half-decomposed (F layer)	
	Equation	R^2	Equation	R^2
P_I	$v = 523.52t^{-0.28}$	0.795	$v = 414.15t^{-0.12}$	0.732
P_{II}	$v = 53.49t^{-0.019}$	0.578	$v = 638.87t^{-0.11}$	0.888
P_{III}	$v = 215.27t^{-0.15}$	0.699	$v = 110.40t^{-0.34}$	0.853
P_{IV}	$v = 141.15t^{-0.18}$	0.813	$v = 260.60t^{-0.22}$	0.777
P_V	$v = 367.01t^{-0.30}$	0.831	$v = 227.44t^{-0.21}$	0.688
P_{VI}	$v = 285.74t^{-0.15}$	0.921	$v = 99.27t^{-0.098}$	0.689
P_{VII}	$v = 53.61t^{-0.071}$	0.678	$v = 215.07t^{-0.12}$	0.721
P_{VIII}	$v = 358.29t^{-0.12}$	0.811	$v = 163.74t^{-0.13}$	0.612
P_{IX}	$v = 281.57t^{-0.14}$	0.542	$v = 157.65t^{-0.23}$	0.733
P_X	$v = 120.67t^{-0.16}$	0.514	$v = 234.61t^{-0.11}$	0.622

tion of P_{III} and P_{IV} plots are obviously better than the others. The litter in P_I plot scored the highest maximum water-holding capacity of 8.23 t/hm^2, equivalent to 0.823mm water depth, and the lowest value of 2.46 t/hm^2 happened in P_{III} plot, equivalent to 0.246 mm water depth. The order of the maximum water-holding capacity was: $P_{III} = P_{IV} > P_X > P_{VII} > P_{IX} > P_{VI} > P_{VII} > P_V > P_{II} > P_I > P_I$ P_{III} plot had the largest maximum effective water-holding capacity, which was 39.39 times higher than that of P_I plot. While the litter in P_{III} plot had the largest total effective interception capability, 6.1 t/hm^2, followed by P_{IV} plot, and the lowest value appeared in P_{II} plot. In our study, the maximum water-holding capacity and the effective interception capability of non-decomposed litter showed the same tendency, and they were higher than those of half-decomposed litter in all plots. But the litter maximum water-holding rate, effective water-holding rate, and water content ratio of all plots had no obvious difference with the variation ranges of 100-154%, 90-161% and 11-44%, respectively. Furthermore, the ranges of the maximum water-holding capacity kept consistent with those of artificial forests in other regions of China (Yang et al. 2003).

***The relationship between the water-holding capacity of litter and its soaking time*:** The changing trend in the water-holding capacity of litter can be described as an S-shape curve with the increase of its soaking time. That means, the water-holding capacity of litter increased quickly within 4 hours before soaking, then decreased steadily, and reached the saturation point within 24 hours (Yang 2007). By means of regression analysis, the relationship between water-holding capacity of litter and its soaking time was determined (Table 4) and the results were driven out by using the equation: $y = a \ln(x) + b$

Where, y is the water-holding depth of litter (mm); x is the soaking time (h); a,b are the coefficients of the equation.

***The relationship between the water absorption rate of litter and its immersion time*:** The fitted relationship between the water absorption rate of litter and its immersion time was calculated (Table 5) by using the following equation:

$$v = b_0 t^{b_1}$$

Where, v is the water absorption rate (g/(kg·h)); t is the immersing time (h); b_0, b_1 are the coefficients of the equation.

Comparison and Analysis of Soil Characteristics and Hydrological Effects of 10 Forest Types

***The influence of afforestation density on soil physical properties*:** The soil bulk density and soil porosity are important parameters to reflect the soil physical properties. They are the major factors for water conservation function and have direct impact on soil aeration and water permeability. In addition, they are also affected by plant species growing more above the ground, decomposition degree of litter and animals and microbes in soil. There are certain differences in the soil bulk density and soil porosity for different forest types (Bai et al. 2009). Table 6 indicates that the soils in P_{III} and P_{IV} plots have relatively greater aeration and water permeability. The maximum capillary water capacity appeared in P_V plot (27.31%) was 2.67 times higher than the minimum one in P_I plot. P_{IV} plot had the highest soil water content of 16.54%, followed by P_{III} plot, and the P_{VI} plot had the lowest value of 8.94%. There was a significant difference in soil capillary porosity, ranging from 12% to 40%. The maximum soil capillary porosity appeared in P_{III} plot, 3.33 times higher than the minimum found in P_I plot. Combined the conclusions above, it showed that the soil structure was greatly improved due to the root system activity of tree and litter decomposition, indicating that the artificial forest played an important role in preventing and controlling desertification. The biggest difference, occurred in factors between 10 forest types, was the soil non-pore porosity. The highest value of 4.32% occurred in P_{II} plot, which was 4.36 times higher than the lowest value appeared in P_{VI} plot. The capillary water capacity and capillary porosity of soil increased with increasing afforestation density and crown density in all plots, except in P_{III} and P_{IV} plots. There was no obvious difference in soil bulk density under different afforestation densities, with the range of 1.10-1.66 g/cm^3.

***The influence of afforestation density on soil water-holding function*:** Due to its loose structure and more water-stable aggregate, forest soil is the main body of forest water conservation and is the decisive factor of water conservation in the forest ecosystem. It has a significant impact on the storage capacity and the input amount of water. And its self-regulating functions of precipitation of forest land reflect the behaviour of the static water conservation function (i.e. water storage capacity), and also the dynamics of adjustment ability (i.e. permeability) (Wei et al. 2008). In Table 7, we can see that the soil in P_{III} and P_{IV} has ideal water storage and infiltration than those of the other plots. P_{IV} plot scored the highest values not only in the maximum water-holding capacity but also in effective water-holding capacity, which were 289.43 t/hm^2 and 60.32 t/hm^2 respectively, followed closely by P_{III} plot. The maximum water-holding capacity of soil in the other plots became larger with the increase of the afforestation density and crown density, except P_{III} and P_{IV} plots. The soil initial infiltration rate of 10 different forest stands was obviously different, ranging from 8.20 mm/min to 16.34 mm/min. The soil stable infiltration rate of all types was 0.11-0.89 mm/min, which was consistent with the results from the previous studies carried on the Loess Plateau (Chen et al. 2005). The maximum soil stable infiltration rate was found in P_{III} plot, which was 8.09 times higher than the minimum appeared in P_{I} plot, the value of which gradually slowed down and reached to steady state after 20 min. Consequently, the main reason of causing the soil infiltration rate is the difference of capillary porosity of various type of soils (Bai et al. 2009).

DISCUSSION AND CONCLUSIONS

Pinus sylvestris var. *mongolica* is one of the main afforestation species in 'Three-North' area of China. It has been introduced and planted in such provinces as Heibei, Shaanxi, Inner Mongolia, Xinjiang, Liaoning and Heilong jiang and it grows fairly well. The afforestation density of *Pinus sylvestris* var. *mongolica* in the study area is 900 to 3600 plants per hectare and the average tree height is 13.26 m. The annual height growth in the study area was estimated to increase up to 30-53 cm in recent 25 years, which was similar to that of artificial forest of *Pinus sylvestris* var. *mongolica* in Zhanggutai town in Liaoning Province. Its growth in the native distributional area is 30-40 cm (Sun 2003). The average DBH is 19.04 cm in the study area, increasing annually by up to 0.46-0.76 cm, which is consistent with the results (i.e., growth by 0.56-0.87cm) from the research on the diameter growth regulation for Mongolian Pine plantation in Hengtou forest farm in Jiamusi city (Chen & Zhu 2010). In general, the artificial forest of *Pinus sylvestris* var. *mongolica*, aged 21 years, in semi-arid sandy desert zone, can grow up evenly to 8.6 m in height, 14.8 cm in DBH, 10.4 m and 25 cm in the largest height and DBH respectively (Sun 2003). At present, the artificial forests in the study area grow very well.

Under the condition of low annual rainfall in Yulin of Shaanxi Province in China; though the weak rainfall intensity cannot make the litter layer saturated, it can make the litter layer to reserve water effectively. The water-holding capacity of forest soil is far greater than that of the litter layer, which is the main body of water resource conservation. Therefore, the reasonable planting density plays a positive role in improving the soil structure and the infiltration capacity of soil (Deng et al. 2014).

The subject matter is: (1) The hydrological effects of

Table 6: The physical properties of the soil under different afforestation densities.

Plot Number	Capillary water capacity(%)	Water content (%)	Bulk density (g/cm^3)	Capillary porosity(%)	Non-pore porosity(%)
P_{I}	10.21±1.23	11.23±1.11	1.23±0.21	12±1	2.34±0.11
P_{II}	11.23±1.34	12.32±1.23	1.32±0.21	15±1	4.32±0.23
P_{III}	23.32±1.44	14.23±1.32	1.42±0.11	40±1	1.02±0.012
P_{IV}	27.31±3.45	16.54±1.32	1.66±0.10	38±2	0.99±0.0019
P_{V}	13.21±2.31	12.11±1.11	1.10±0.11	21±4	2.13±0.13
P_{VI}	14.23±2.13	8.94±1.10	1.21±0.10	15±3	2.44±0.32
P_{VII}	15.32±3.21	9.32±0.99	1.23±0.099	17±1	3.45±0.43
P_{VIII}	16.32±3.21	9.80±2.10	1.45±0.039	18±1	3.65±0.455
P_{IX}	17.65±3.45	11.23±1.11	1.56±0.12	21±3	4.00±0.89
P_{X}	20.32±4.23	10.32±1.23	1.66±0.18	23±2	2.78±0.32

Table 7: The water storage and infiltration characteristics of the soil under different afforestation densities.

Plot Number	Maximum water-holding capacity(t/hm^2)	Effective water-holding capacity(t/hm^2)	Initial infiltration rate(mm/min)	Stable infiltration rate(mm/min)
P_{I}	200.43	38.39±3.23	8.20±1.23	0.11±0.021
P_{II}	210.34	34.21±3.45	10.21±1.11	0.20±0.011
P_{III}	267.32	53.45±3.33	15.32±2.31	0.89±0.021
P_{IV}	289.43	60.32±6.43	16.32±2.31	0.78±0.034
P_{V}	220.23	40.32±4.21	11.32±1.21	0.66±0.044
P_{VI}	230.32	38.21±4.21	12.34±1.10	0.54±0.021
P_{VII}	233.22	33.21±3.00	14.32±1.21	0.32±0.022
P_{VIII}	241.45	31.43±2.89	15.45±3.21	0.45±0.044
P_{IX}	250.65	28.19±2.65	12.00±1.21	0.33±0.021
P_{X}	266.43	29.99±2.65	16.34±3.22	0.24±0.010

forest litter and soil in P_{III} and P_{IV} plots were the best and the optimal afforestation density was 1500 to 1800 plants/hm^2, while the worst was found in P_I plot (3600 plants/hm^2). (2) There was a good regression relationship between both water absorption rate of litter and its immersion time, and also between the water-holding capacity of litter and its soaking time. (3) There were obvious differences in soil capillary porosity and non-pore porosity, and the difference of capillary porosity of various types of soil was the main reason affecting the soil infiltration rate.

It shows that the artificial forests under different afforestation densities in the study area grow very well, especially in P_{III} and P_{IV} plots, where the decomposition speed of litter was the fastest and the soil had better storage potential. It is helpful for forest to combat sandy land degradation, to restore the vegetation, and plays an important role in the ecological and economic benefits of water conservation. However, under the condition of less rainfall, scarce water resources and fragile ecological environment in Yulin of Shaanxi Province in China, the late growth will be limited because of the fierce competition for water, nutrient and growth space between trees with increasing afforestation density and crown density. So controlling or managing of density is very important in forest plantation. Thinning should be done timely and appropriately to prevent the recession of forest stand. Besides, it is unapproachable whether *Pinus sylvestris* var. *mongolica* can be planted in large scale or in high density, and whether the best afforestation density is 1500 to 1800 plants/hm^2. Further research should be taken to confirm the speculations.

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