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Hydrologic Effects of a Korean Pine Plantation in Northeast China

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Abstract

By examining, over time, the distribution process of precipitation patterns, as obtained from numerous systematic experiments, the ecological function and effects of precipitation on a plantation ecosystem could be determined.

The relationship between precipitation in the stand and outer areas, as well as the characteristics of the surface runoff in the Korean pine plantation were studied in the Laoshan Experimental Forests located near the Northeast Forestry University of China. Results showed that the distribution of precipitation in the Korean pine plantation had its own special characteristics and regulation pattern. The average canopy interception rate was about 13.4% and the stem flow rate was about 5.3%. A significant linear relationship was observed between the stand and outer areas for gross precipitation rates. When compared to that of a larch plantation, the snow interception rate in the Korean pine plantation was 33.3%. The surface runoff rate in the Korean pine plantation decreased by 58.8% compared relatively to that of the outer wasteland, consequently, the surface runoff was negligible.

Key words: Korean pine, Plantation, precipitation Hydrologic observation, Surface runoff

Introduction

The hydrologic effect on a plantation is an important function of the forest ecosystem. Research on the forest hydrology has been widely developed in New Zealand (Rowe 1983), German (Schulze *et al.* 1978), America (Leonard 1961, Hervey and Patric 1965, Hervey 1968, Rogerson and Byrnes 1968), and in Japan (Nakano 1977). For a long time, particularly the relationship between forests and waters has been a great concern (Horton 1919, Richard 1980). However, hydrology research in the field concerning forests and water distribution began later in China and has since become a popular area of study. Until now, most of the research in this area has been done in Northeast China, and centered on the old-growth forest of Korean pine trees and the natural secondary forests. However, the hydrologic effects on plantations have rarely been investigated in Chinese forests. Therefore, this study examined the hydrologic effects of a Korean pine plantation in order to improve the reforestation of pine trees, and to evaluate the ecological benefits associated with reforestation practice, and judicious forest management.

This paper reports only a brief description of systematic investigations that have been carried out in the Korean pine forest involving long-term fixed observation data collected from over many years. The particulars mainly include the distribution process of precipitation, relationship between precipitation in the inner and outer stand, as well as the characteristics of surface runoff in a Korean pine plantation in the Laoshan Experimental Forests (LEF) belonging to Northeast Forestry University.

Study sites and Methods

Study sites

All the trials and observation were carried out in the LEF. It is located at Laoshan between 127° 30′ and 127° 34′ longitude and between 45° 20′ and 45° 25′ latitude with a total area of nearly 6000 ha. A typical Korean pine plantation was selected as a fixed trial plot (Table 1). At the same time, the outer wasteland around the same site with an area of 0.1ha was chosen as the contrast plot.

Methods

An observation tower was built in the stand. The Gross precipitation was measured by using pluviometers, which were fixed at the top of the tower. Considering the distribution features of the canopy layers, ten pluviometers were systematically placed in the stand, and the average rainfall defined as the through fall. Ten sample trees were selected according to the equal proportion of trunk diameter-class to measure the rate of stem flow. A circular channel runoff-measuring instrument was fixed on the trunk, with polyvinyl chloride (PVC) directing water into a container.

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Table 1. Main character of the experimental plot

Species	Area (ha)	Altitude (m)	Soil type	Slope degree	Spacing	Reserved Individuals	Age	Height	$D_{1.3}$	Coverage
Korean pine	0.1	350	Bleached soil	5°	1.0*1.5	152	30a	14.0	13.2	0.9

Two rectangular sample compartments of 0.1 ha were established separately in the stand, the contrast area, which was circumfused under the ground with 1.2m plastic boards. There were no vegetables in the contrast compartments. The surface runoff was gathered and observed at the corner in the low slope of the compartments, when the precipitation took place. The observation term began in 1985.

Results

Effect on the precipitation distribution from Canopy

Table 2 shows that the total through fall in one year was 555.9 mm in the Korean pine plantation, which accounted for 81.3% of the gross precipitation rates. The stem flow rate was 36.2 mm, which was 5.3% of gross precipitation rates. This low stem flow rate could be attributed mainly to the soft and coarse nature of the Korean pine bark as well as large moisture storage capacity. The annual canopy interception of the Korean pine plantation was 91.7 mm, which was 13.4% of gross precipitation rate. Our results indicate that there were apparent differences between the Korean pine plantation and a fir plantation in canopy interference in relation to the rainfall distribution. The interception rate of the fir plantation was 10%(Huang *et al.*, 1993).

The through fall and stem flow rates increased as the gross precipitation increased. However, during the rainy season, the variance was smaller, only ranges from 75.0% - 83.2% and 3.5% - 6.4% for through fall and stem flow rates, respectively. The peak value of through fall rate was registered in July when the gross precipitation was the largest, where as the stem flow rate peaked in August. This difference was mainly due to the higher precipitation during July, which resulted in a higher moisture content in the forest in August. Contrary to the through fall rate and stem flow rate, the interception rate was highest in April and October. This was mostly due to the slight precipitation, which occurred during this period. The interception rate was relatively low during the higher precipitation intensity and frequency observed in the months of July and August. In the whole transformation cycle, the canopy interception rate changed in the range of 10.6% - 21.5%.

Relationships between the through fall and the gross precipitation

The dynamics of the through fall were influenced by the gross precipitation, which showed in certain regulations (Table 3). From the collected data, a regression analysis was carried out on the precipitation distribution depicted as different amounts of rainfall.

The results show that there was an apparent linear relationship between the through fall and the gross precipitation.

$P_1 = -1.9486 + 0.9414P$, $r = 0.9964^* > r_{0.01} = 0.835$;

$P_2 = -0.1014 + 0.0537P$, $r = 0.9940^* > r_{0.01} = 0.764$;

$P_3 = 0.9336 + 0.0802P$, $r = 0.9348 > r_{0.01} = 0.792$.

Notes: P_1 through fall ; P_2 stem flow ; P_3 canopy interception ; P gross precipitation;

* is significant correlation

The through fall and stem flow rates were

Table 2. Distribution of monthly precipitation in the Korean pine plantation

Items	Month							Total
	4	5	6	7	8	9	10	
Precipitation/mm	23.5	60.0	106.5	198.0	190.3	82.7	22.8	683.8
Through fall/mm	17.9	47.4	85.3	164.7	158.0	65.5	17.1	555.9
%	76.1	78.9	80.1	83.2	83.0	79.2	75.0	81.3
Stem flow/mm	0.8	2.4	5.6	10.5	12.6	3.5	0.8	36.2
%	3.5	4.0	5.3	5.3	6.4	4.2	3.5	5.3
Interception/mm	4.8	10.2	15.6	22.8	19.7	13.7	4.9	91.7
%	20.4	17.1	14.6	11.5	10.6	16.6	21.5	13.4

Notes: All the data in the table are average value of 10 years observed from 1985 to 1994.

Table 3. Precipitations distribution of the Korean pine plantation in different raining-grade

Raining-grade (mm)	Times	Through fall		Stem flow		Canopy interception	
		mm	%	mm	%	mm	%
0.52	40	0.17	29.3	0	0	0.42	72.4
2.12	106	1.03	48.6	0.03	1.4	1.06	50.0
4.26	107	2.98	70.0	0.08	1.9	1.20	28.2
7.69	104	5.88	76.5	0.27	3.5	1.54	20.0
12.27	78	6.60	78.2	0.47	3.8	2.20	17.9
17.49	62	14.36	82.1	0.83	4.7	2.30	13.2
25.26	62	21.10	83.2	1.10	4.4	3.15	12.5
33.77	20	28.32	83.9	1.67	4.9	3.78	11.2
48.95	21	40.04	81.8	2.98	5.1	6.42	13.1
68.03	11	60.07	88.3	3.60	5.2	4.36	6.4
87.70	5	74.76	85.3	4.40	5.0	8.54	9.7

Table 4. Distribution of different precipitation in the Korean pine plantation

Year	Precipitation forms	Gross precipitation	Through fall		Stem flow		Canopy interception	
			(mm)	(%)	(mm)	(%)	(mm)	(%)
1985	rain	577.0	476.0	79.1	31.0	5.4	70.0	12.1
	snow	57.7	37.5	–	–	–	20.2	35.0
1986	rain	666.0	526.0	79.0	48.0	7.2	92.0	13.8
	snow	47.3	34.0	–	–	–	13.3	28.1
1987	rain	783.0	622.0	78.3	63.0	8.0	108.0	13.8
	snow	10.2	7.9	–	–	–	2.3	22.5
1988	rain	819.0	856.0	80.1	49.0	5.5	120.0	14.6
	snow	31.3	19.9	–	–	–	11.4	36.4
1989	rain	646.0	525.0	81.3	41.0	6.3	80.0	12.4
	snow	56.1	35.5	–	–	–	20.6	36.9
1990	rain	934.0	740.0	79.2	58.0	6.2	134.0	14.3
	snow	85.5	54.9	–	–	–	30.6	35.8
1991	rain	666.0	528.0	79.3	42.0	6.3	90.0	14.4
	snow	34.9	21.6	–	–	–	13.3	38.1

estimated and measured according to the gross precipitation. The regression equations show that the canopy interception rate decreased with the increase of the gross precipitation. When the gross precipitation was less than 13mm, the canopy interception rate decreased sharply as the gross precipitation increased. Nevertheless, the canopy interception rate gradually reached a steady state and fluctuated after that. The stem flow had a tendency to heighten with the increase of the gross precipitation. However, it was hardly noticeable when the gross precipitation was less than 2mm. Stem flow increased significantly in proportion to the increase of actual rainfall before the gross precipitation reached 13 mm, and then it essentially reached a plateau, despite showing some slight fluctuations. The reason for these fluctuations was that the high rainfall grade mainly occurred in July and August, when the intensity and frequency of the precipitation and the moisture of needles and branches were higher. Therefore, these results in the canopy rate, through fall and stem flow were fluctuating regularly. This is in accordance with the annual dynamics of the precipitation distribution.

The interception effect of the canopy on different forms of the precipitation

In the northeast China, precipitation takes two forms, rain and snow. The distribution process of snow differs evidently from the rain in the forest and can be described as a solid precipitation. It only includes two parts such as through fall and canopy interception.

The snow interception capacity of the Korean pine canopy was much more than that of the canopy interception (Table 4). The snow interception rate of the canopy changes in the range of 22.5%~38.1% and the average rates were 33.3%. The canopy interception rate ranged from 12.1% to 14.6%, and was 13.6% on average.

The annual dynamics of the canopy snow interception are shown in table 4. The canopy interception rate increased gradually with time. This was mostly due to the increase of the trees' ages and the thickness of the canopy, the quantity of branches and the constant increase in the number of leaves. The reason that the canopy snow interception rate decreased in 1990 was that a thinning treatment was carried out in the winter of 1989. But the ability of canopy snow interception in the Korean pine plantation was restored very quickly after the thinning according to later observations.

Influence of different rainfall grades on the surface runoff

Surface runoff in the Korean pine plantation in this district is usually storage runoff (Yang 1978, Zhou 1994). If the rainfall speed does not exceed the final infiltration, it would output in a way such as though-flow or groundwater runoff. If the rainfall intensity does exceeds the final infiltration speed, and then it would create the surface runoff.

The surface runoff cannot take place when the precipitation is less than 2mm, whether in the forestland or wasteland. It heightens with the increase of the precipitation. However, the wasteland surface runoffs of different rainfall grades were all higher than that of the forestland. The surface runoff rate in the Korean pine plantation was reduced by 58.8% more than that of the outer wasteland (Table 5).

Through the calculation and analysis, it can be concluded that the formation and quantity of the surface runoff was directly related to the gross precipitation, so it is possible to predict the surface runoff according to the model.

In the Korean pine plantation:

$P_1 = -0.0065 + 0.0012P \quad r = 0.9718^* > r_{0.01} = 0.735$

In the outer wasteland:

$P_1 = -0.0190 + 0.0019P \quad r = 0.9438^* > r_{0.01} = 0.725$

Notes: P_1 the surface runoff, P gross precipitation.

* a greatly significant correlation

Conclusions

The distribution pattern of precipitation in the Korean pine plantation has its own characteristics and specific regulation. The average rate of the canopy interception, the stem flow rate, and the through fall rate was 13.4%, 5.3%, and 81.3%, respectively. Our results demonstrated that there is an obvious and direct relationship between the through fall and the gross precipitation in the Korean pine plantation. Contrary to larch plantation findings (Ding 1989), the capacity of snow interception in the Korean pine plantation was obviously greater than that of water interception rates. The average snow interception was 33.3%.

The surface runoff in the Korean pine plantation was slight. It only occurred in the season with the higher precipitation intensity. The surface runoff rate decreased 58.8% as compared to that of the outer watershed areas. Our results suggested that the direct beat of the rainstorm on the forestland and the splash erosion of the raindrops as well as the washing-away of the runoff could be significantly reduced and weakened by the canopy interception. Secondly, the decomposed forest litter can protect the ground surface from erosion by holding the water it has collected. Furthermore, in the plantation, the capacity of the soil's water storage and percolation was very great which allowed a certain amount of rainfall to permeate into the soil and flow into the river as a form of latent through-flow.

Table 5. Comparison of surface runoffs of the forestland and wasteland

Gross precipitation (mm)	Forestland surface runoff		Wasteland surface runoff	
	(mm)	(%)	(mm)	(%)
0.58	0	0	0	0
2.12	0	0	0	0
4.26	0.001	0.02	0.002	0.05
7.69	0.007	0.09	0.011	0.14
12.27	0.008	0.07	0.016	0.13
17.49	0.017	0.10	0.051	0.29
25.26	0.029	0.11	0.093	0.37
33.77	0.025	0.10	0.094	0.28
48.95	0.041	0.08	0.114	0.23
68.03	0.083	0.12	0.140	0.21
87.70	0.104	0.12	0.147	0.17
Average	–	0.07	–	0.17

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