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Effects of forest on precipitation chemistry and total suspended particles of stem-flow in Jiufeng National Forest Park, Beijing

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Abstract Precipitation chemistry was monitored in two different types of forests (mixed *Pinus tabulaeformis* and *Quercus variabilis* forest and pure *Q. variabilis* forest) in Jiufeng National Forest Park, in western Beijing. Results showed that the pH value of precipitation ranged between 6.13 and 6.97 and no acid rain appeared; the mean electrical conductivity (EC) was 0.18 mS/cm and mean total suspended particles (TSP) was 44.02 mg/L, but these values changed significantly with different amounts of stem-flow. Acidification occurred in the stem-flow to different extents: that of *P. tabulaeformis* > *Q. variabilis*. The mean EC value of stem-flow in *P. tabulaeformis* in the mixed forest was 1.00 mS/cm, which was 5.88 times as high as that of precipitation outside the forest. EC values of *Q. variabilis* in pure and mixed forests show little difference, 0.34 and 0.30 mS/cm, respectively and were 2.00 and 1.76 times higher than that of precipitation. During the summer, EC values of stem-flow of *P. tabulaeformis* decreased over time and with an increase in the amount of precipitation. The mean TSP of stem-flow in mixed forest was 116.95 mg/L, but 87.14 mg/L in the pure forest, which were 72.93 and 43.12 mg/L higher than that of precipitation.

Keywords precipitation, stem-flow, pH value, EC value, total suspended particles

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1 Introduction

Forests can act as sinks for air pollutants and pollutant transportation involves many complicated biological, chemical and physical processes (Smith, 1986). In recent years, many scholars have investigated the function of woody plants in cities and suburbs as a sink for air pollutants in the capacity of sink and related factors. As a result of interaction with plants and the atmosphere, the chemical composition of rain changes after it passes through the canopy and stems of trees (Puckett, 1990). The pH, electric conductivity (EC) and total suspended particles (TSP) can be considered as the main parameters indicating these changes (Amezaga, 1997). In China, there are many reports on the ecological benefits of urban trees, but we have not seen any related reports in the suburban areas of Beijing. This study mainly focuses on two forest stands: one is a mixed conifer broadleaf deciduous plantation (*Pinus tabulaeformis* and *Quercus variabilis*) and the other is a purely deciduous broadleaved plantation (*Q. variabilis*) in the Jiufeng National Forest Park, Beijing. The effects of the forest on the acidity of precipitation, conductivity and the capacity to deposit air pollutants were studied. This will also lay the foundation for scientifically managing and evaluating ecological benefits of forests.

2 Study area

Jiufeng National Forest Park (39°54' N, 116°28' E) is situated in the northwest suburb of Beijing, the north end of the Taihang mountain and the east end of the Yanshan mountain, at an elevation of 1,153 m. The upper part of the mountain is mainly covered by granite and tuff, while the lower part is covered by sandstone and limestone. Brown soil is mainly distributed in the zone above 900 m in elevation. A typical warm-temperate continental monsoon climate with distinct seasons dominates this site. The average annual temperature is 12.2°C. Annual rainfall is about 700 mm, mainly occurring in July and August. Forest coverage is 56.3%, the current

vegetation is largely an artificial forest planted between the 1950s and the 1960s. The main species are *P. tabulaeformis*, *Platycladus orientalis*, and *Q. variabilis*.

3 Materials and methods

3.1 Plot setting and sampling

Two plots (20 m × 20 m) in two plantations were set at an elevation above 400 m in sunny slopes with the same slope degree of about 20°. One plot was in the mixed *P. tabulaeformis* and *Q. variabilis* plantation and the other in the pure *Q. variabilis* plantation. Both plantations were 31 years old. In the pure *Q. variabilis* plantation, the average diameter at breast height (DBH) and height (H) were 13.4 cm and 10.5 m and coverage was 0.82. In the mixed *P. tabulaeformis* and *Q. variabilis* plantation, the coverage was 0.84 and the average DBH and H of *P. tabulaeformis* were 11.4 cm and 8.9 m and 20.6 cm and 12.8 m for *Q. variabilis*. Water samples of stem-flow were collected from four sample trees and in each tree, split polythene pipes were tightly enlaced on the stem to conduct the stem-flow to a 22-L plastic container; then, the contents of the four containers were mixed together to form the final sample for analysis. Precipitation was collected by two rain gauges placed at a vacant site outside the forest. Water from the two rain gauges was also mixed to form the final rainfall sample. A total of 54 water samples collected 12 times between May and July in 2003 were used to analyze pH, EC and TSP.

3.2 Sample analysis

All the samples collected were measured immediately. If time did not permit, these samples were filtered and put in polyethylene containers, deposited at 2–5°C in a refrigerator and were measured within 6 h. Filtered suspended particles were dried in an oven at 103–105°C (Wei, 1989).

The pH values were measured using an ORION868 pH meter, EC values using a DDS-304 electric conductivity meter and the suspended particles were weighted with a digital balance.

4 Results and analysis

4.1 Change in pH

Precipitation, especially heavy and prolonged rain, had strong a cleaning effect on suspended particles in the atmosphere and the suspended particles affected the pH of precipitation (Galloway, 1995). The pH of precipitation outside the forest was 6.56 on average; the maximum was 6.97 and the minimum 6.13, which indicated that the precipitation was neutral and the suspended particles did not change its pH. There was one acid precipitation with a pH of 5.77 on 20 July 2003, which was due to the water being blown by strong winds from the canopy into the containers. After precipitation through the canopy and stem-flow, the pH changed (Fig. 1). There was no clear similar change in pH values of precipitation and stem-flow (Fig. 1). In the mixed plantation, the pH of stem-flow collected ranged from 4.76–6.92 in the *P. tabulaeformis* plantation, while it ranged between 5.70 and 6.89 in the *Q. variabilis* plantation. In the pure plantation, the pH of stem-flow was 5.61–7.21, which indicated that acidification happened in the stem-flow. This result agrees with those of Fan (2000) and Feng (1999). With regard to pH, there are no clear differences among precipitation and stem-flow of *P. tabulaeformis*, and stem-flow of *Q. variabilis* $F < F_{0.05} = 2.87$ (sample size $n = 40$).

Differences in pH between precipitation and stem-flow were caused by suspended particles retained on the canopy and tree bark (Sanislaw, 2001). Acidity of stem-flow can be used as a parameter of bio-indicators of air pollution (Steubing, 1982). It is also believed that the secretion of organic acids might contribute to the acidification of stem-flow. The reason for the acidity of stem-flow should be studied further.

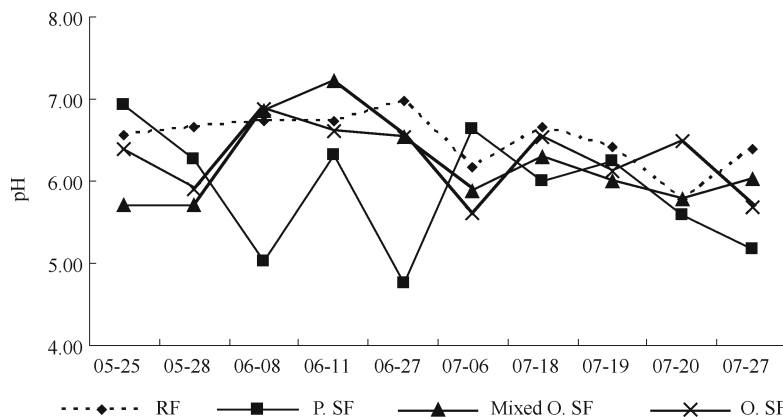


Fig. 1 pH values of stem-flow in different plantations
 RF is rainfall, P. SF is *P. tabulaeformis* stem-flow, mixed O. SF is mixed *Q. variabilis* stem-flow, O. SF is *Q. variabilis* stem-flow.

Table 1 Change in EC values of stem-flow in different plantations (unit: mS/cm)

Item	Rainfall outside forest	Mixed plantation		Pure plantation
		<i>P. tabulaeformis</i> stem-flow	Mixed <i>Q. variabilis</i> stem-flow	<i>Q. variabilis</i> stem-flow
Minimum	0.08	0.22	0.09	0.13
Maximum	0.42	3.40	0.64	0.67
Average	0.17	1.00	0.30	0.34

From a regression analysis of pH, a correlation coefficient $r = 0.209$ between the precipitation and *P. tabulaeformis* stem-flow was obtained; $r = 0.552$ between the precipitation and *Q. variabilis* stem-flow in the mixed plantation and 0.357 between the precipitation and *Q. variabilis* stem-flow in the pure *Q. variabilis* plantation. These results imply that with regard to pH there was no apparent correlation between precipitation and stem-flow.

4.2 Change in EC

Electric conductivity (EC) is a comprehensive parameter used to reflect the number and activities of ions. The EC value of rain changes greatly when precipitation passes through the canopy of a forest (Table 1).

The average EC value of precipitation is 0.17 mS/cm. In the mixed plantation, the EC value of stem-flow of *P. tabulaeformis* and *Q. variabilis* is 5.88 times and 2.00 times as high as that of precipitation; in the pure *Q. variabilis* plantation it is 1.76 times. There are apparent differences among precipitation on the one hand and stem-flows of *P. tabulaeformis*, and *Q. variabilis* on the other ($F > F_{0.01} = 4.38$ ($n = 40$)).

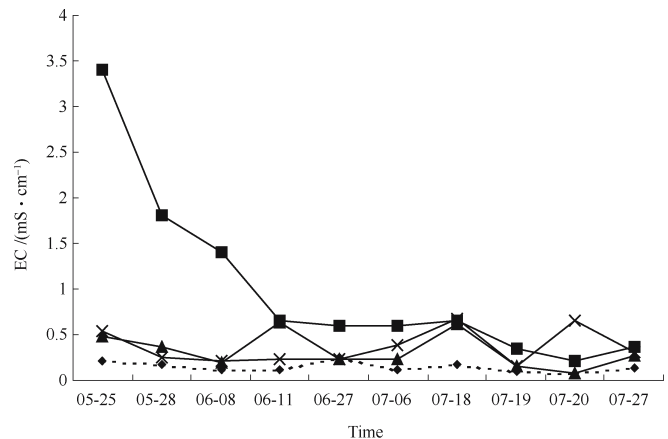
The analysis and multiple comparisons by *Q* tests of the EC values showed that the correlation was significant between the stem-flow of *P. tabulaeformis* and precipitation, notably between the stem-flow of *P. tabulaeformis* and that of *Q. variabilis*, but insignificant between the stem-flow of *Q. variabilis* and precipitation, which indicates that the density and composition of ions in the stem-flow of *P. tabulaeformis* were greater than those of *Q. variabilis*. Some experts (Liu and Yu, 2001) believe that when precipitation passes through the forest, (1) their ions may be condensed with water evaporation or (2) it may wash or leach the dust and the secretion adhered to the branches, trunks, stems and the leaves. We believe that this is also related to the species types in the forest. *Q. variabilis* and *P. tabulaeformis* have different secretions in regard to quantity and composition; hence, *P. tabulaeformis* had less stem-flow and higher a EC value than *Q. variabilis* (Table 2).

Regression analysis showed that in the mixed plantation the correlation coefficients r were 0.506 and 0.380 between precipitation and stem-flow of *P. tabulaeformis* and *Q. variabilis*; in the pure *Q. variabilis* plantation $r = 0.039$. We conclude that the EC between precipitation and stem-flow were obviously not correlated.

Table 2 Difference in EC value of rainfall, stem-flow of *P. tabulaeformis* and *Q. variabilis*

	Average	Significance	
		0.05	0.01
<i>P. tabulaeformis</i> SF	1.003	a	A
<i>Q. variabilis</i> SF	0.361	bcd	AB
Mixed <i>Q. variabilis</i> SF	0.328	cd	AB
RF	0.151	d	B

The value of EC is related to the ion composition of precipitation. In summer, along with an increase in precipitation, especially the stem-flow of *P. tabulaeformis* and the EC value showed a decreasing trend (Fig. 2).

**Fig. 2** Variation in EC values of stem-flow

4.3 Change in TSP

TSP as solid material cannot pass through a designated filter. The TSP value of stem-flow was remarkably higher than that of precipitation (Fig. 3).

The TSP values of stem-flow of the mixed plantation and pure *Q. variabilis* plantation were 116.95 and 87.14 mg/L on average and were, respectively, 72.93 and 43.12 mg/L higher than those of precipitation. Because the sample size was not large enough for a statistical *Q* test, we cannot conclude anything about their relationship.

The data above show that forests have a distinct effect of refreshing the air. It is reported that forests can store, filter and adsorb dust; *P. tabulaeformis* plantations can store 96 t/hm²

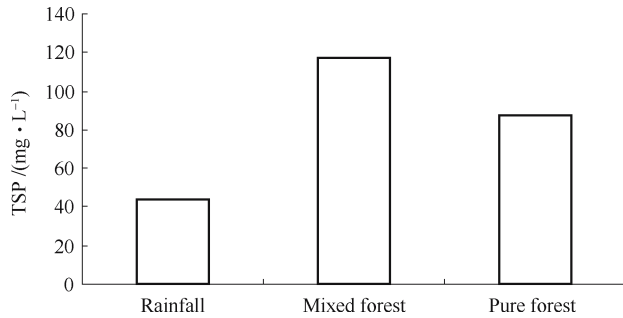


Fig. 3 Contents of total suspended particles of stem-flow in different plantations

each year while *Ulmus alba* can store 3.03 g/m² of dust every day (Liu, 2001). Urban forests play an important role in improving city environments, especially in severely polluted cities. Different forest stands have different capacities in sequestering suspended particles. Our study showed that mixed plantations had a higher capacity than pure plantations to store dust. Some investigators believe that this mainly results from the difference in their biological characteristics (Liu and Yu, 2001). They argued that although *P. tabulaeformis* usually has a small total leaf area, it had a sticky secretion around the needles and branches to hold dust easily. It is believed that *P. tabulaeformis* usually has a denser and a bigger canopy, more twigs and coarser bark than *Q. variabilis* and its clustered needles also played an important role in storing dust.

The pattern of the TSP of precipitation and stem-flow are not similar. From a regression analysis we obtained their correlation coefficient r ; in the mixed plantation it was 0.548 and in the pure *Q. variabilis* plantation it was 0.283. We did not find a strong correlation because the forest itself performed different roles in collecting TSP.

5 Conclusions and discussion

The average pH of precipitation was 6.56 and ranged from 6.13 to 6.97. The mean EC and TSP values of precipitation were 0.18 mS/cm and 44.02 mg/L.

The values of pH, EC and TSP change significantly after precipitation passes through a forest. Stem-flow has a lower pH than precipitation. Usually the stem-flow of *P. tabulaeformis* was more acidic than that of *Q. variabilis*.

The mean EC value of stem-flow of *P. tabulaeformis* in mixed plantation was 1.00 mS/cm, which was 5.6 times as high as that of precipitation. The EC values of *Q. variabilis* in pure and mixed plantations were 0.34 and 0.30 mS/cm respectively and were 1.9 and 1.7 times as high as that of precipitation.

In summer, the EC of stem-flow of *P. tabulaeformis* decreases with the approaching rainy season, but this phenomenon did not occur in the stem-flow of *Q. variabilis*.

The mean TSP of stem-flow in mixed plantation was 116.95 mg/L, while it was 87.14 mg/L in the pure *Q. variabilis* plantation and 72.93 and 43.12 mg/L higher than that in precipitation, respectively, which showed that the two forest stands have a different capacity for storing suspended particles. The mixed plantation has a higher capacity for storing suspended particles.

Acid rain will be the main target for and at the edge of scientific research in this century. This phenomenon is occurring in southern China and in parts of northern China. Studies and monitoring of acid rain in the Jiufeng National Forest Park should be continued.

Forests can be effectively used as a sink to deposit suspended particles. Our research is only at its initial stage. Detailed research should cover the whole year and other related factors, such as wind speed and direction, should be studied further.

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