

NIE Lishui, WANG Dengzhi, LI Jiyue

Transfer characteristics of nutrient elements through hydrological process of a *Pinus tabulaeformis* stand in the West Mountain of Beijing

© Higher Education Press and Springer-Verlag 2007

Abstract Forest precipitation chemistry is a major issue in forest hydrology and forest ecology. Chemical contents in precipitation change significantly when different kinds of external chemical materials are added, removed, translocated and transformed to or in the forest ecosystem along with precipitation. The chemistry of precipitation was monitored and analyzed in a 31-year-old *Pinus tabulaeformis* forest in the West Mountain of Beijing. Movement patterns of nutrient elements in hydrological processes can be discovered by studying this monitored data. Also, the information is useful for diagnosing the function of ecosystems and evaluating the impact of the environment on the ecosystem.

Samples of rainfall, throughfall and stemflow were collected on the site. In the lab, Ca^{2+} and Mg^{2+} were analyzed by flame atomic absorption and K^+ and Na^+ by flame emission. $\text{NH}_4^+\text{-N}$ was analyzed by indophenol blue colorimetry and $\text{NO}_3^-\text{-N}$ was analyzed by phenoldisulfonic acid colorimetry. The results showed that: 1) The concentration gradient of nutrient elements clearly changed except for Na^+ . The nutrients in stemflow were significantly higher than those of throughfall and rainfall as the precipitation passed through the *P. tabulaeformis* forest. The monthly patterns showed distinct differentiation. There are indications that a large amount of nutrients was leached from the canopy, which is a critical function of intra-ecosystem nutrient cycling to improve the efficiency of nutrient use. 2) The concentrations of $\text{NO}_3^-\text{-N}$ and K^+ changed more than those of the other nutrient elements. The concentration of $\text{NO}_3^-\text{-N}$ in throughfall and stemflow was 4.4 times and 9.9 times higher than those in

rainfall, respectively. The concentration of K^+ in throughfall and stemflow was 4.1 times and 8.1 times higher than those in rainfall, respectively. 3) The leaching of nutrient elements from the stand was an important aspect of nutrient return to the *P. tabulaeformis* forest, which returned a total amount of nutrient of 54.1 kg/hm^2 , with the contribution of Ca^{2+} and K^+ much greater than that of other elements. Also, K^+ was the most active element in leaching intensity. 4) Nutrient input through precipitation was the main source in the West Mountain of Beijing and the amount of nutrient added was 66.4 kg/hm^2 , of which Ca^{2+} and N contributed much more than the other nutrient elements. When precipitation passes through the *P. tabulaeformis* forest, 121 kg/hm^2 of nutrient is added to the forest floor. Ca^{2+} recorded the greatest nutrient increase, with 61.2 kg/hm^2 , followed by N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$), K^+ and Mg^{2+} , with 31.3 and 16.5, and 8.11 kg/hm^2 , respectively. The least was Na^+ , 3.34 kg/hm^2 .

Keywords *Pinus tabulaeformis*, nutrient elements, movement, leaching, throughfall, stemflow

1 Introduction

Circulation of water, nutrients and the transformation of energy are basic processes of an ecosystem that maintains a consistent production of organic matter. To understand the nature and quantity of the biogeochemical processes of precipitation, it is necessary to understand the sustainable development of the productivity of the ecosystem. Precipitation deposits, transports and exports various materials to or from the outside to the ecosystem. The canopy of the forest serves as a filter and provides an interface for the deposition of dust from the air (Radzi et al., 1992; Ander et al., 2000). The chemical composition of precipitation changes distinctly as the result of interception, absorption and leaching while the precipitation passes through the canopy (Ander et al., 2000; Xu et al., 2001). This change also depends on the type of precipitation and its chemical composition, structure and

Translated from *Acta Ecologica Sinica*, 2006, 26(7): 2,101–2,107 [译自: 生态学报]

NIE Lishui (✉), WANG Dengzhi
College of Water and Soil Conservation, Beijing Forestry University,
Beijing 100083, China
E-mail: nielishui@sohu.com

LI Jiyue
College of Forest Resources and Environment, Beijing Forestry
University, Beijing 100083, China

physiological function of the forest (Friedland, 1991). By analyzing these changes we can obtain information about both the function of the ecosystem and the effect of the environment on the ecosystem.

Jiufeng National Forest Park is the forest park nearest to Beijing. It is very famous both as a tourist attraction and for ecological values. The soundness of ecological systems directly affects human life. *P. tabulaeformis* is one of the typical established species in the Huabei vegetation district. Some authors have carried out studies about the chemical properties of precipitation in the other regions of Beijing (Li, 1998; Liu, 2001). Our objective is to discover the process of nutrients cycling through precipitation in the ecosystem of a pure pine stand. By doing this we can provide some evidence in understanding the functions of this system. In this way, we hope that we can manage this ecosystem better at a sustainable level and increase future incomes from tourism for this park.

2 Study area and methods

2.1 Site description

Jiufeng National Forest Park is 30 km from the city and situated in the north-western outskirts of Beijing (east longitude 116°28', north latitude 39°54') (<http://www.jsdj.com/luyou/lyzy/bjjiufeng.htm>). It is located at the Miaofeng Mountain which forms the connection of the north end of the Taihang Mountains and the east end of the Yanshan Mountains. The summit of the Miaofeng Mountain is 1,153 m above sea level. This site has a typical warm-temperate continental monsoon climate. It is a semi-arid site at the lower part of the mountain (under 500–900 m above sea level) and semi-humid in the upper part. The aridity index is between 1–1.5. The four seasons are clearly demarcated. It is warm, dry and windy in the spring but warm and humid in the summer. It is sunny and humid in the fall but cold and dry in the winter. The mean annual temperature is 11.7°C. The highest temperature ever recorded was 39.7°C and the lowest –19.6°C. Annual rainfall is about 645 mm with a peak in July and September.

The study site was at 465 m above sea level, located on the north slope of Yanling peak. It is part of the Jiufeng National Forest Park. The parent material is in the form of slope deposits of mixed weathering material of granite, tuff and limestone. Brown soil is mainly distributed in areas 900 m above sea level and below this level consists of mountain cinnamon soil. This site had a typical warm-temperate continental monsoon climate. The soil is leached cinnamon soil. Soil pH is between 6.4 and 8.4. The vegetation is a mixed conifer and deciduous broadleaf forest mainly composed of pine (*Pinus tabulaeformis*), oak (*Quercus variabilis*) and cypress (*Platycladus orientalis*), etc. The plot is a pure, 31 year-old, pine (*Pinus tabulaeformis*) forest. The average tree height is 8.7 m, the average diameter at breast height is 14.7 cm with a density of 1,625 trees/hm². There are some shrubs under the pine trees: *Myriopholis dioica* Bunge, *Spiraea dasyantha* Bunge

and *Cyperus* L. The thickness of the forest litter is 3–5 cm of an L-F type.

2.2 Sample methods

All the information used in this paper is based on long-term site monitoring data collected between April and October of 2004 at the Jiufeng Forest Ecosystem Research Station. Precipitation, used as check water samples, was collected by two rain gauges placed in a vacant spot outside the forest. Each time water was collected from the two rain gauges, it was mixed to form a final sample for analysis. The throughfall was collected in three plastic troughs (200 cm × 20 cm × 20 cm) located under the canopy. Throughfall water was mixed, sampled and measured by volume. Stemflow water samples were chosen from five standard trees of average diameter. Split polythene pipes, tightly circling the stem of trees, were used to conduct the stemflow to the down end where a 22-L plastic container was used to collect the stemflow. The water was fully mixed by shaking the containers before these stemflow water samples were collected in plastic bottles. The plastic bottles had been dipped in 1:5 nitric acid for three days and washed by distilled water. After analyzing the water samples we washed the bottle twice before using them again. Water samples were collected after each rainfall. We made 27 collections for a total of 81 water samples.

2.3 Analytical methods

Samples of rainfall, throughfall and stemflow were collected on the site and brought to the lab the same day. Samples were filtered in the laboratory. Ca²⁺ and Mg²⁺ were analyzed by flame atomic absorption and K⁺ and Na⁺ by flame emission. NH₄⁺-N was analyzed by indophenol blue colorimetry and NO₃⁻-N was analyzed by phenoldisulfonic acid colorimetry. All analyses were carried out the same day as the samples were collected.

3 Results and analysis

3.1 Changes in nutrient concentration in throughfall and stemflow

When precipitation passes through the canopy of the forest stand it changes to throughfall and stemflow. The concentration of their nutrients such as K⁺, Na⁺, Ca²⁺, Mg²⁺, NH₄⁺-N, NO₃⁻-N change dramatically.

As shown in Fig. 1, except for Na⁺, all nutrient elements showed a clear change in concentration as the precipitation changed into throughfall and stemflow in a gradient where stemflow > throughfall > precipitation. The amount of nutrient both in the throughfall and the stemflow had a clear monthly pattern. It seems that all nutrients have the same monthly pattern. Amounts of nutrient in both the throughfall and the stemflow were high in April. Followed by the increase of precipitation, the amount of nutrients decreased to its

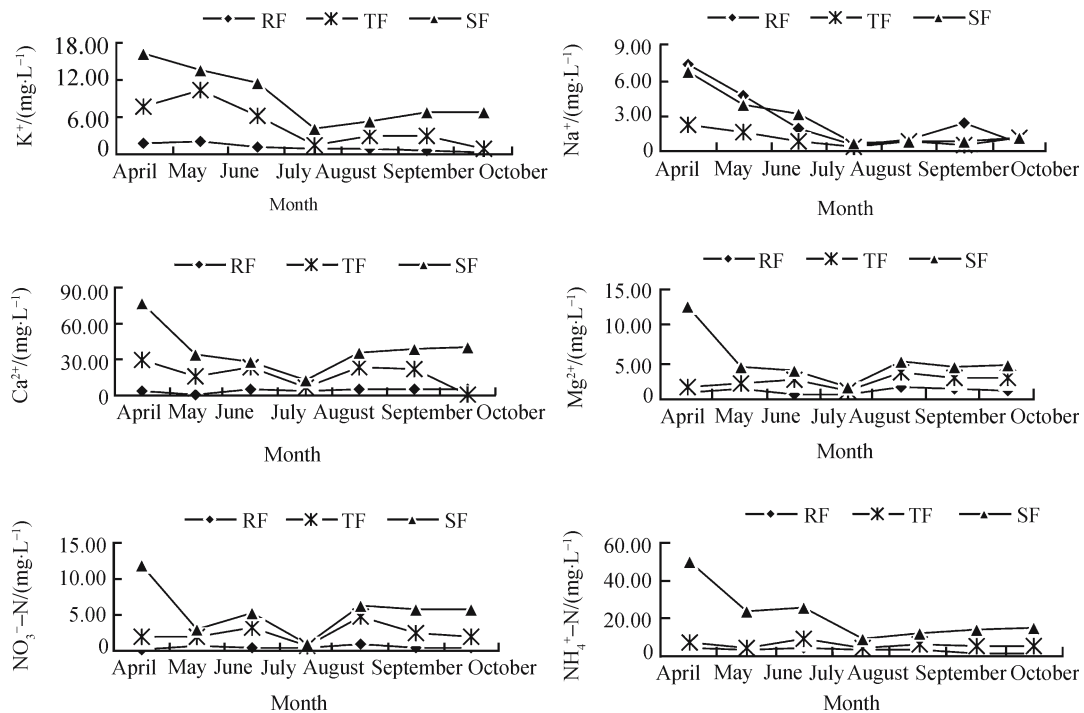


Fig. 1 Monthly variation in nutrient concentration of throughfall and stemflow in *Pinus tabulaeformis*. RF: rainfall; TF: throughfall; SF: stemflow

lowest level in July. This result agreed with the research on the chemical properties of precipitation in pine forests on Dongling Mountain (Huang, 2000). The amount of nutrient in our region has a clearer seasonal pattern than that of the tropics and subtropical regions (Chen, 1998; Li, 1998). The various amounts of nutrients change differently both in the throughfall and the stemflow.

Concentration of K⁺

The concentration of K⁺ in the precipitation was the highest in April, when it was 1.86 mg/L, while it decreased to its lowest level in July when it was 0.77 mg/L. It increased again after July. Both the concentration of K⁺ in the throughfall and the stemflow have a similar changing pattern. They were 7.58 mg/L and 16.21 mg/L in April, which were four times and eight times that of precipitation, respectively. They decreased to 1.55 mg/L and 3.99 mg/L in July, which were both still two times that of precipitation. The concentrations of K⁺ between precipitation and throughfall or stemflow collected between April and October showed statistically very significant differences in a one-way analysis of variance (ANOVA) ($p < 0.001$; $n = 27$). This indicated that K⁺ moved very much in the plant and circulated rapidly in the forest ecosystem.

Concentration of Na⁺

Na⁺ and K⁺ both moved about very much in the plant where they exist as ions. The concentration of Na⁺ in the precipitation was higher than both that of the throughfall and the stemflow during all months except in June. This was different from the other nutrients. That the concentrations of Na⁺ both in the throughfall and stemflow were lower than that of precipitation may indicate that precipitation may leach out

Na⁺ from the pine trees. The concentration of Na⁺ in the precipitation was 7.35 mg/L. It decreased to its lowest level in July with a concentration of 0.67 mg/L. The concentration of Na⁺ in the throughfall and the stemflow were comparatively higher at 2.33 mg/L and 6.67 mg/L, respectively. Both the throughfall and the stemflow had about the same concentration of Na⁺ after July. There were no distinct changes in Na⁺ concentration as precipitation changed to throughfall and stemflow.

Concentration of Ca²⁺

The Ca²⁺ in the precipitation mainly originated from dust and organic matter in the air. The concentration of Ca²⁺ in the precipitation had an even monthly pattern with an average concentration of 4.97 mg/L from April to October. The concentration of Ca²⁺ both in the throughfall and the stemflow had a distinct monthly pattern of change. The concentrations of Ca²⁺ in the throughfall and the stemflow were comparatively higher at 30.64 mg/L and 77.28 mg/L, respectively. They were about six times and 16 times higher than those in precipitation. They decreased to their lowest level in July when they were 7.83 mg/L and 13.47 mg/L, respectively and 1.6 and 2.7 times higher than that of precipitation. After July, the concentration slowly increased but it was still lower than that in April. The concentrations of Ca²⁺ between the precipitation and the throughfall or the stemflow collected between April and October showed very significant differences statistically in a one-way ANOVA ($p < 0.001$; $n = 27$). Ca²⁺ serves as a bridge among the pectin, which is one of the main components of the cell wall. It has a low solubility and mobility and is usually deposited in the stems of the trees. Circulation of Ca²⁺ was slower than that of K⁺ and Na⁺ (Zhou, 2002).

Concentration of Mg^{2+}

Mg^{2+} is also one of those nutrient elements resistant to dissolving or leaching. The monthly patterns of the concentration of Mg^{2+} in the precipitation and the stemflow were similar to that of Ca^{2+} . The concentration of Mg^{2+} in the precipitation was 1.22 mg/L. The concentration of Mg^{2+} in the stemflow was the highest with 12.56 mg/L in April. Other months had low and evenly distributed concentrations. The concentration of Mg^{2+} in the throughfall was low in April. Other months had evenly distributed concentrations. The concentrations of Mg^{2+} between precipitation and throughfall or stemflow collected between April and October showed statistically very significant differences in a one-way ANOVA ($p < 0.001$; $n = 27$).

Concentration of NO_3^- -N

Compared with other nutrient elements, the concentration of NO_3^- -N in precipitation was very low, 0.57 mg/L on average from April to October. It was high in August with a value of 1.12 mg/L. The concentration of NO_3^- -N in the throughfall and the stemflow were lowest in July which was 0.74 mg/L and 1.13 mg/L, respectively. The concentration of NO_3^- -N in the stemflow was the highest in April. It was 12.03 mg/L, six times higher than that of throughfall. The concentrations of NO_3^- -N between the precipitation and the throughfall or the stemflow collected between April and October showed very significant differences as seen from a one-way ANOVA ($p < 0.001$; $n = 27$).

Concentration of NH_4^+ -N

The same as with NO_3^- -N, the concentration of NH_4^+ -N in the precipitation, throughfall and stemflow had a distinct monthly pattern. However, the concentration of NH_4^+ -N was, on average, 3.44 mg/L, which was six times higher than that of the NO_3^- -N. The concentration of NH_4^+ -N in the throughfall had an even monthly pattern of change and varied between 5.03 and 9.70 from April to October. In contrast, the concentration of NH_4^+ -N in the stemflow had a wide range in its monthly pattern of change. The concentration of NH_4^+ -N in the stemflow was 50.78 mg/L which was 13 times higher than that of the precipitation. The concentrations of NH_4^+ -N between the precipitation and the throughfall or the stemflow collected between April and October showed very significant differences statistically in a one-way ANOVA ($p < 0.001$; $n = 27$). Fan (2000) studied the effect of a Chinese fir forest on the chemical properties of precipitation and Jiang (2003) the chemical properties of precipitation on an evergreen

forest. Their results showed that the concentration of NH_4^+ -N, NO_3^- -N in precipitation was higher than that of the throughfall and the stemflow. This conclusion is different from our research. This may due to the fact that different ages of the evergreen forest need different amounts of NH_4^+ -N, NO_3^- -N.

After precipitation passes through the canopy and runs down the stem, the level of nutrient concentrations in precipitation changes greatly. In our study, NO_3^- -N showed the biggest change in concentration. The concentration of NO_3^- -N in the throughfall and the stemflow were 4.4 times and 9.9 times that of precipitation from the air. The concentration of K^+ in the throughfall and stemflow were 4.1 time and 8.1 times that of precipitation from the air. The concentration of Ca^{2+} in the throughfall and stemflow were 3.7 times and 7.9 times that of precipitation from the air (Table 1). The differences in concentrations of all nutrient elements between precipitation and throughfall or stemflow collected between April and October were, statistically, highly significant as shown from a one-way ANOVA ($p < 0.001$; $n = 27$). This indicated that the forest ecosystem had a clear effect on the circulation of nutrients. This result agreed with the studies conducted by Liu et al. (2001a, 2001b) on a pine forest and a chestnut forest. His research also showed that N^+ and K^+ had the largest change in concentration after precipitation changed to throughfall and stemflow. It indicated that precipitation has an eluviation effect and more nutrients were added as it passed through the pine canopy. There are many studies in this field (Lawrence, 1991; Neary, 1994; Marks, 2000), which shows that nutrient enrichment may be caused by leaching from the leaves, addition of dust intercepted by the trunks and secretions from the stems. This process involves a complicated absorption and deposition mechanism. It is one of the chemical regulating processes in the enrichment of forest land.

3.2 Leaching effect of precipitation on the canopy

When precipitation passes through the canopy it will leach nutrients. These nutrients are dissolved in the water and can be easily reused by the trees through root absorption. This eluviation can be quantified and expressed as net input eluviation, which is the input of throughfall and stemflow minus the input by precipitation from the air. The intensity of the eluviation can be expressed as net input eluviation (D_R) (Li, 1998).

Table 1 Ratio of nutrient concentration of throughfall, stemflow to precipitation in *Pinus tabulaeformis* (unit: $mg \cdot L^{-1}$)

Nutrient elements	Concentration of precipitation	Throughfall		Stemflow	
		Concentration	TF/RF	Concentration	SF/RF
K^+	1.13 (0.28)	4.60 (1.12)	4.07	9.15 (1.17)	8.10
Na^+	2.70 (0.81)	1.15 (0.59)	0.43	2.56 (0.40)	0.95
Ca^{2+}	4.97 (0.98)	18.5 (3.74)	3.72	39.32 (5.45)	7.91
Mg^{2+}	1.22 (0.22)	2.52 (0.43)	2.07	5.30 (0.83)	4.34
NO_3^- -N	0.57 (0.14)	2.52 (0.58)	4.42	5.67 (0.89)	9.95
NH_4^+ -N	3.44 (0.57)	6.56 (1.12)	1.91	21.79 (2.93)	6.33

Note: Standard errors in parenthesis

Table 2 Nutrient input by precipitation of *Pinus tabulaeformis* (unit: kg·hm⁻²)

Nutrient elements	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻ -N	NH ₄ ⁺ -N	Total
Input of precipitation	5.51	10	23.96	5.41	3.23	18.27	66.38
Input of throughfall	15.4	3.09	55.66	7.47	7.00	20.89	109.51
Input of stemflow	1.09	0.25	5.56	0.64	0.8	2.65	10.99
Net input of eluviation	10.98	-6.66	37.26	2.70	4.57	5.27	54.12
Net D	1.99	-0.67	1.56	0.50	1.41	0.29	0.82
Total input	16.49	3.34	61.22	8.11	7.80	23.54	120.5

Net input eluviation ratio (D_R) = input of throughfall and stemflow/input of precipitation

During the research period, the net input eluviation was 54.12 kg/hm². Different nutrients contributed different amounts to net input eluviation. Ca²⁺ has the highest net input eluviation with 37.26 kg/hm². K⁺ was the second with a net input eluviation of 10.98 kg/hm². The net input eluviations of NH₄⁺-N and NO₃⁻-N were similar, 5.27 kg/hm² and 4.57 kg/hm². The net input eluviation of Mg²⁺ at 2.70 kg/hm² was low and that of Na⁺ negative at -6.66 kg/hm². This may indicate that Na⁺ was absorbed by the canopy (Table 2). Usually, K⁺ has a higher solubility and moves about in the plant. It is easily leached from the leaves of the plant. It is often thought that K⁺ has a higher net input of eluviation than that of Ca²⁺. Because Ca²⁺ is slowly released and is more difficult to leach than K⁺, it usually has a lower net input eluviation than K⁺. In our study Ca²⁺ recorded a higher net input eluviation than K⁺. This may be caused by the addition of Ca²⁺ by suspended particles blown from the soil and derived from limestone and tuff in the area.

The various nutrients have different eluviation intensity expressed by D_R (Table 2). K⁺ had the largest D_R , which was about 2. Ca²⁺ and NO₃⁻-N had a similar D_R , 1.56 and 1.41, respectively. D_R of Na⁺ was negative.

The leaching of nutrients from the canopy by precipitation can facilitate biological cycling of nutrients. Hence, it can help to improve plant growth. However, too much leaching may have a negative effect for it may deplete the nutrient reserves in tissues and may further cause a nutrient deficiency syndrome (Cronan, 1983, 1995). If the forest was to receive acid rain over a long period, its nutrients may become heavily depleted and cause a serious nutrient deficiency and further decrease productivity of the forest (Liu, 2000). Up to the present, acid rain has not been found in the West Mountain. We still suggest that a monitoring system be set up at the forest ecosystem research station.

3.3 Nutrient input rate of precipitation, throughfall and stemflow

Precipitation changes its composition when it passes through the forest canopy. It also adds amounts of nutrients to the forest land under the canopy. Usually, the input of nutrients in mountainous forest lands largely comes from the decomposition of litter and a small amount from precipitation. Because pine needles are resistant to decomposition by organisms, the

input of nutrients by precipitation plays an important role in nutrient cycling. The input of nutrients by precipitation includes precipitation from the atmosphere, throughfall, and stemflow.

From Table 2 we see that the total input of nutrient by precipitation from the atmosphere was 66.38 kg/hm². The highest annual amount was Ca²⁺ with 23.96 kg/hm², with N (NH₄⁺-N+NO₃⁻-N) ranked in second place with 21.50 kg/hm² per year and Na⁺ in third place with an input rate of 10.00 kg/hm² per year. The annual input rates of K⁺ and Mg²⁺ were similar with an input rate of 5.51 kg/hm² and 5.41 kg/hm², respectively.

The total nutrient input rate by throughfall was 109.51 kg/hm² in the study period. The input rate of Ca²⁺ was 55.66 kg/hm² accounting for 50% of the total input. The input rate of N was 27.89 kg/hm², 25% of the total input. The input rate of NH₄⁺-N was three times that of NO₃⁻-N. The input rate of K⁺ and Na⁺ were 15.4 kg/hm² and 3.09 kg/hm², respectively. K⁺ accounted for 14% of the total input rate (Table 2).

The total nutrient input rate by stemflow was 10.99 kg/hm² (Table 2) and the input rate of each nutrient element showed the same trend, both in magnitude and ratio, as that of throughfall. The nutrient input rate of the throughfall was ten times that of stemflow. Throughfall contributed much more nutrients than stemflow. The nutrient brought by the stemflow could reach the system of tree roots and was easily absorbed by the roots. This was especially important in the dry season.

The total input of nutrients of the forest land by stemflow and throughfall was 120.50 kg·hm⁻² per year. The highest input rate was Ca²⁺ with an annual rate of 61.22 kg/hm². N (NH₄⁺-N+NO₃⁻-N) ranked second with an annual input rate of 31.34 kg/hm² per year while the input rate of NH₄⁺-N was three times that of the NO₃⁻-N. The total amount of N is equal to applied urea at a rate of 68.13 kg/hm² per year. The annual input rates of K⁺, Mg²⁺, Na⁺ were 16.49 kg/hm², 8.11 kg/hm², 3.34 kg/hm², respectively. Ca²⁺, K⁺, Mg²⁺, Na⁺ accounted for 50.80%, 26.01%, 13.68%, 6.73%, and 2.77% of the total input, respectively.

4 Discussion

1) The amount of nutrient elements of K⁺, Na⁺, Ca²⁺, Mg²⁺, NH₄⁺-N, NO₃⁻-N changes after precipitation passes through

the pine forest canopy. Except for Na^+ , all elements had a clear gradient of concentration changes. The changes in the amount of nutrient were ranked from high to low as follows: stemflow > throughfall > precipitation. The amount of nutrient changes of both stemflow and throughfall had a clear and similar monthly pattern of change. The amounts of nutrient among precipitation, stemflow and throughfall varied greatly.

2) The amount of NO_3^- -N recorded the highest change. It increased by 4.4 times and 9.9 times after precipitation changed into throughfall and stemflow, respectively. K^+ , Ca^{2+} increased by 4.1 times and 3.7 times after precipitation changed to throughfall; it increased 8.1 times and 7.9 times, respectively, after precipitation changed to stemflow. There was little change in Na^+ . We normally believe that K would show the greatest changes in concentration but our study showed that NO_3^- -N had the greatest change. It was clear that its amount of nutrient increased greatly after precipitation passed through the canopy.

3) There was a total of 54.12 kg/hm² of nutrient leached from the canopy when precipitation passed through in the study period. The intensity of leaching was as follows: $\text{Ca}^{2+} > \text{K}^+ > \text{NH}_4^+$ -N > NO_3^- -N > $\text{Mg}^{2+} > \text{Na}^+$. K^+ was the highest leaching element while Na^+ was absorbed by trees.

4) The input of nutrient to the forest ecosystem included both dry deposition and wet deposition. Precipitation was the main form of wet deposition. There was 66.38 kg/hm² of nutrient input annually by precipitation directly from the air. The highest amount was from Ca^{2+} with 23.96 kg/hm² annually with N (NH_4^+ -N + NO_3^- -N) ranked second with 21.50 kg/hm² per year and Na^+ ranked third with an input rate of 10.00 kg/hm² per year. The annual input rates of K^+ and Mg^{2+} were similar at 5.51 kg/hm² and 5.41 kg/hm², respectively.

5) The total input of nutrients to the forest land by stemflow and throughfall was 120.50 kg/hm² per year. The nutrient input rate of the stemflow was ten times higher than that of the throughfall. This input may come from dry deposition, wet deposition or the leaching from the surface of the leaves and the bark of the trees. The highest input rate was by Ca^{2+} with an annual rate of 61.22 kg/hm². N (NH_4^+ -N + NO_3^- -N) ranked second with an annual input rate of 31.34 kg/hm² per year while the input rate of NH_4^+ -N was three times that of NO_3^- -N. The total N was equal to applied urea at a rate of 68.13 kg/hm² per year. The annual input rates of K^+ , Mg^{2+} , Na^+ were 16.49 kg/hm², 8.11 kg/hm², 3.34 kg/hm², respectively.

We have records of a decrease in precipitation since 1999. In 2002 the annual rainfall was 512.8 mm and 417.6 mm in 2003. However, it was comparatively high in 2004 with an annual rainfall of 585.5 mm. Even in that year, we just recorded one surface runoff. It indicates that runoff plays a minor role in nutrient cycling. That is the reason why we narrowed our research of nutrient cycling to stemflow and throughfall.

References

- Castro M, Morgan R P (2000). Input-output budgets of major ions for a forested watershed in Western Maryland. *Water Air Soil Pollut*, 119: 121–137
- Chen B F, Zeng Q B, Huang Q, Zh G Y (1998). Hydro-ecological effect of tropical mountain rain forest ecosystem—Canopy leaching, hydrochemical storage. *Acta Ecol Sin*, 18(4): 364–370 (in Chinese)
- Cronan C S, Grigal D F (1995). Use of calcium aluminum ratios as indicators of stress in forest ecosystems. *J Environ Qual*, 24: 209–226
- Cronan C S, Reiner W A (1983). Canopy processing of acidic precipitation by coniferous and hard-wood forests in New England. *Oecologia*, 59: 216–223
- Fan H B (2000). Effect of canopy interception by Chinese fir forests on precipitation chemistry. *Sci Silv Sin*, 36(4): 2–8 (in Chinese)
- Friedland A J, Miller E K, Battles J J (1991). Nitrogen deposition, distribution and cycling in a subalpine spruce-fir forest in the Adirondacks, New York, USA. *Biogeochemistry*, 14: 31–55
- Gonzalez-Arias A, Amezcaga I, Echeandia A (2000). Buffering capacity through cation leaching of *Pinus radiata* D. Don canopy. *Plant Ecol*, 149: 23–42
- Huang J H, Li H T, Han X G, Chen L Z (2000). Nutrient characteristics of stemflow and throughfall in two coniferous forest ecosystem. *Acta Phytocool Sin*, 24(2): 248–251 (in Chinese)
- Jiang W H (2003). Chemical properties of acid rain in evergreen broad-leaved forest in Simianshan mountain and the effect of acid rain on soil and vegetation. Dissertation for the Master's Degree. Beijing: Beijing Forestry University
- Lawrence G B, Fernandez I J (1991). Biogeochemical interactions between acidic deposition and a low-elevation spruce-fir stand in Howland, Maine. *Can J For Res*, 21: 867
- Li H T (1998). Study on hydrology of mountain forest ecosystem in warm temperate zone. Dissertation for the Doctoral Degree. Beijing: National Library
- Li L H, Lin P (1998). Throughfall and stemflow nutrient depositions to soil in a subtropical evergreen broadleaved forest in the Wuyi Mountains. *J Environ Sci*, 10(4): 426–432
- Liu J X, Wen D Z, Zhou G Y (2000). Chemical properties of rainfall in the coniferous and broad-leaved forests in acid rain area of Heshan, Guangdong. *China Environ Sci*, 20(3): 198–202 (in Chinese)
- Liu S H (2001). Studies on Aquatic Chemistry and Biochemistry Cycle of Water Resources Protection Forest in Miyun Reservoir Beijing. Dissertation for the Doctoral Degree. Beijing: Beijing Forestry University
- Liu S H, Yu X X, Yu Z M (2001a). Properties of water chemical elements of *Castanea mollissima* forest in Miyun reservoir watershed. *J Beijing For Univ*, 23(2): 12–15 (in Chinese)
- Liu S H, Yu X X, Yu Z M (2001b). Chemical properties of precipitation in *Pinus tabulaeformis* water resource protection forest in Miyun reservoir watershed. *Chin J Appl Ecol*, 12(5): 697–700 (in Chinese)
- Neary A J, Gizyn W I (1994). Throughfall and stemflow chemistry under deciduous and coniferous forest canopies in south-central Ontario. *Can J For Res*, 24: 1089
- Radzi Abas M, Ahmad-Shah A, Nor Awang M (1992). Fluxes of ions in precipitation, throughfall and stemflow in an urban forest in Kuala Lumpur, Malaysia. *Environ Poll*, 75: 209–213
- Wang D Z, Nie L S, Li J Y (2005). Effects of forest on chemical properties of precipitation and total suspended particles of stemflow in Jiufeng National Forest Park. *J Beijing For Univ*, 27(1): 89–91 (in Chinese)
- Xu Y G., Zhou G Y, Wu Z M, Luo T S (2001). Chemical composition of precipitation, throughfall and soil solutions at two forested sites in Guangzhou, South China. *Water Air Soil Poll*, 130: 1,079–1,084
- Zhou G Y, Yan J H (2001). The influence of regional atmospheric precipitation characteristic and its element inputs on the existence and development of Dinghushan forest ecosystems. *Acta Ecol Sin*, 21(12): 2,002–2,012 (in Chinese)