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Original Research

Effects of Forest Transformation on the Fluxes of Potassium, Calcium, Sodium, and Magnesium Along with Rainfall Partitioning

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Abstract

Rainfall partitioning is an important pathway of the cycling of base cations in forest ecosystems, as base cations can be rapidly transferred from forest canopy to forest floor along with throughfall and stemflow, replenishing nutrients to soils. These processes can be greatly affected by forest transformation through, for example, altering the structure of forest canopy, but how forest transformation may affect the fluxes of base cations along with rainfall partitioning is rarely addressed in the literature. To evaluate the impacts of forest transformation on base cation cycling with rainfall partitioning, we monitored the concentrations and fluxes of four common base cations, namely potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+), of rainfall, throughfall, stemflow, and surface runoff in four types of subtropical forests (*Castanopsis carlesii* natural forest, *C. carlesii* secondary forest, *C. carlesii* plantation, and *Cunninghamia lanceolata* plantation) after forest transformations during the period from April 2021 to March 2022. The results showed that (1) the amount of throughfall, stemflow, and surface runoff varied significantly among different forest types under essentially the same rainfall conditions; (2) K^+, Ca^{2+}, and Mg^{2+} were leached in the canopy, while Na^+ was absorbed in the canopy during the one-year study period; (3) the net throughfall flux (NTF) of K^+ and Na^+ were the largest in the *C. carlesii* natural forest, while the NTF of Ca^{2+} and Mg^{2+} were the largest in the *Cun. lanceolata* plantation, and base cations of the NTF were smaller in *C. carlesii* secondary forest and *C. carlesii* plantation. Overall, the transformation of *C. carlesii* natural forest to *C. carlesii* secondary forest and *C. carlesii* plantation reduced the NTF of base cations and increased the fluxes of base cations in surface runoff, which may

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pose a risk of declining the ecological service functions of *C. carlesii* secondary forest and *C. carlesii* plantation.

Keywords: base cations, throughfall, stemflow, surface runoff, canopy exchange

Introduction

Rainfall partitioning creates important hydrological channels for nutrient migration and cycling in forest ecosystems [1]. When rainfall enters the forest, most of it does not directly reach the forest floor due to the obstruction of tree canopy and trunk [2], but is partitioned into throughfall, stemflow, and interceptions [3-4]. Interception returns to the atmosphere through evaporation [5], while throughfall and stemflow downward to provide hydrological conditions for nutrients transport from canopy to forest floor [6-7]. The formation of throughfall and stemflow can not only wash off the dry deposition on the surface of leaves and trunks, but the exchange of ions also happens with plant tissues [8-10]. The chemical composition of throughfall and stemflow thus often changes considerably compared with rainfall [8, 10]. As essential nutrients for plant growth and health, the deficiency of base cations such as potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+) will adversely affect the long-term productivity of forests [11-13]. While it is gratifying that base cations accumulation often occurred in throughfall and stemflow, which can replenish the forest soil base cations in the areas where soil base cations loss is serious [14-15]. As a part of rainfall partitioning, surface runoff does not account for a high proportion of rainfall amount in forest ecosystems under high vegetation [16], yet it is a major pathway for base cation loss in forests because it can leach large amounts of base cations from decomposing litter during the formation of surface runoff [17-18].

The alteration in the chemical composition of rainfall as it passes through the canopy has greatly resulted from various factors, including rainfall characteristics, canopy structure, site conditions, and atmospheric deposition [8-9, 19-20]. Rainfall and forest canopy, as matter transport carriers and the main place where rainfall partitioning occurs, respectively, are the two major factors affecting the net rainfall input of base cations in forest ecosystems [20-22]. When rainfall is small and evaporation is strong, most of the rainwater was intercepted on canopy without the formation of throughfall and stemflow and transport of base cations. Also, the seasonal rainfall pattern can lead to seasonal changes of base cations fluxes [9]. In addition, the chemical composition of rainfall also significantly affects the base cations exchange that occurs in the canopy [23-24]. Forest canopy characteristics are another essential factor affecting forest base cation fluxes. Differences in canopy structure lead to possible variations in dry deposition accumulation at the canopy level [25], while differences in canopy ion leaching or uptake characteristics among tree species may also result in significant divergence in canopy fluxes to the forest floor [26].

Forest transformation is a direct driver of the alteration of forest canopy, and can change the original forest landscape and forest canopy structure in a short period, significantly affecting ion fluxes along with rainfall partitioning during the first phase of a forest transformation process [27]. It has been shown that the early stages of natural forest transformation to secondary forest or plantation can negatively affect soil phosphorus fractions, soil organic carbon, carbon sequestration, and plant diversity [28-30]. However, till now, little attention has been paid to the effects of natural forest transformation to secondary forest and plantation on the fluxes of base cations along with rainfall partitioning in forest ecosystems.

Here, we conducted a field experiment to test the hypothesis that changes in canopy structure caused by forest transformation affect forest rainfall partitioning patterns and canopy exchange of base cations. We continuously monitored rainfall partitioning in four types of forests, namely a *Castanopsis carlesii* natural forest and three forests transformed from natural forests, i.e., a *C. carlesii* secondary forest, a *C. carlesii* plantation, and a *Cunninghamia lanceolata* plantation, and tested the concentrations and calculated the fluxes of four common base cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) of rainfall, throughfall, stemflow, and surface runoff in these forests. We also evaluated the potential drivers of base cation fluxes in throughfall as affected by forest transformation. This study contributes to a better understanding of the factors that affect the fluxes of base cations in different subtropical forest types during rainfall partitioning processes, and also provides a scientific basis for sustainable forest management.

Material and Methods

Study Site

The study was conducted at subtropical forests at the Sanming Research Station of Forest Ecosystem and Global Change of Fujian Normal University in Sanming City, Fujian Province, Southeast China. This area has a subtropical monsoon climate with a mean annual temperature of 19.3ºC and a mean annual rainfall of 1610 mm. The rainfall here has an obvious distinction between rainy (from March to August) and dry seasons, with 80% of the total rainfall amount occurring in raining season [16]. The forests in this area are mainly subtropical evergreen broad-leaved forests, and the dominant tree species is *C. carlesii*. Since 1958, massive evergreen broad-leaved forests have been cut down and have been transformed to secondary forests or plantations We compared the base cation fluxes of throughfall, stemflow, and surface runoff in the four forest types, namely *C. carlesii* natural forest, *C. carlesii* secondary forest, *C. carlesii* plantation, and *Cun. lanceolata* plantation. The *C. carlesii* secondary forest, *C. carlesii* plantation, and *Cun. lanceolata* plantation were all transformed from *C. carlesii* natural forests. We constructed three 20 × 20 m plots for each type of forest, and all the constructed plots have similar slopes. Table 1 shows the tree characteristics, pH of soil, and litter volume of the four forest types.

Experimental Design

From April 2021 to March 2022, the water amount of rainfall, throughfall, and stemflow were monitored by tipping bucket rainfall sensors (Fengyun, Shanghai). Three tipping bucket rainfall sensors were placed on the cleaning site next to the forest for recording rainfall. In each plot, we randomly placed 3 grooves with a length of 4 m and a width of 0.15 m, and the bottom of the grooves was connected to the tipping bucket rainfall sensor with rubber tubes to collect and record throughfall. We selected 5 trees covering a wide range (4.4-37.7 cm) of diameter at breast height (DBH) in each plot, cut the rubber pipe, and fixed it in a circle and a half at a height of 1.3 m. The rubber tubing was connected to tipping bucket rainfall sensors to record trunk stemflow, and a funnel and a 10 L plastic bucket were placed under the tipping bucket rainfall sensor to collect water for chemical analysis.

A 20 × 5 m surface runoff plot was built in each plot, and PVC boards with a height of 60 cm and a thickness of 7 mm were embedded in the soil around the runoff plot to form a closed runoff plot, aiming to distinguish the inside and outside of the runoff plot. A trapezoidal collecting tank is constructed with PVC boards below the runoff plot, and a stainless steel bucket with a length, width, and height of 1 m is placed horizontally below the collecting tank to undertake surface runoff water. At the end of each rainfall event, the water depth in the stainless steel bucket was measured to calculate the surface runoff amount generated by a single quadrat.

Chemical Analysis and Calculation

After each rainfall event, water samples were immediately collected from plastic buckets using 250 ml plastic bottles that had been cleaned with deionized water. The collected water samples were filtered through 0.45 μm polypropylene membranes, and then the concentrations of K^+, Ca^{2+}, Mg^{2+}, and Na^+ were determined by plasma emission spectrometry (ICP-OES, Horiba JY, France).

The fluxes of K^+, Ca^{2+}, Mg^{2+}, and Na^+ transferred to the forest ecosystem after per rainfall event was calculated by multiplying the concentration of ions by the amount of water:

$$F = C \times V \times 10^{-2} \quad (1)$$

where F represents the flux (kg/ha) of a certain base cation, C represents the concentration (mg/L) of a certain base cation and V is the depth (mm) of rainfall, throughfall, stemflow or surface runoff for a given event.

The net throughfall flux (NTF) represents the amount of nutrients transported from the canopy to the forest floor and is equal to the difference between ion flux in throughfall (TF) plus ion flux in stemflow (SF) and ion flux in rainfall (RF) [9]:

$$NTF = TF + SF - RF \quad (2)$$

Statistical Analysis

We used linear mixed-effects models to compare the differences in throughfall, stemflow, or surface runoff among the four forest types, and to examine the differences in concentrations and fluxes of base cations among the four forest types [31]. When using linear

Table 1. The tree characteristics, pH of soil, and litter volume of the four forest types.

Forest types	*Castanopsis carlesii* natural forest	*C. carlesii* secondary forest	C. *carlesii* plantation	*Cunninghamia lanceolata* plantation
Slope (°)	31.7	32	33	31.7
Stand density (No./hm^2)	3788	13300	2400	2860
Forest age (year)	45	10	10	10
Diameter at breast height (cm)	21.99	5.07	9.93	14.8
Tree height (m)	15.8	7.87	8.77	11.3
Canopy density	0.8	0.7	0.6	0.6
pH of soil	4.76	4.79	4.75	4.74
Litter volume in growing season (kg/hm^2)	3628.2	3119.3	2317.0	1140.6

mixed-effects model, we set the sampling time as the random-effect factor and forest type as the fixed factor. When significant differences were found, we used Tukey's HSD for post hoc comparisons. In addition, we used random forest model to test the importance of different driving factors (rainfall characteristics, wind speed, temperature, humidity, stand density, diameter at breast height, and tree height) on the fluxes of base cations [32]. All data analyses were performed in R 4.0.3.

Results

Patterns of Rainfall Event and Partitioning

A total of 36 rainfall events were recorded during the study period, amounting to 1242.67 mm of rainfall, while water samples for throughfall, stemflow, and surface runoff were collected only in 36, 34, and 31 times of the total rainfall events, respectively (Fig. 1). The throughfall of different forest types accounted for 65.8 to 76.0% of total rainfall amount, while the stemflow accounted only for 1.3 to 6.0% and surface runoff for 0.5 to 0.8% of total rainfall amount. Analysis of the linear mixed-effects models showed that forest type had a significant effect on forest rainfall partitioning ($p<0.001$). Among the four forest types, the largest amount of throughfall was produced by *Cun. lanceolata* plantation, which was significantly higher than that produced by the *C. carlesii* secondary forest and the *C. carlesii* natural forest. The stemflow of the *C. carlesii* secondary forestand *C. carlesii* natural forests was significantly higher than that of the *C. carlesii* plantation, and *Cun. lanceolata* plantation. Likewise, the surface runoff from *C. carlesii* secondary forest and *C. carlesii* natural forests was significantly higher than that from *C. carlesii* plantation, and *Cun. lanceolata* plantation. The specific magnitude of the values is shown in Table 2.

Concentration Dynamics of Base Cations

The concentrations of K^+, Ca^{2+}, Na^+, and Mg^{2+} varied strongly among different months (Fig. 2). The concentrations of base cations in throughfall, stemflow, and surface runoff among four forest types had significant differences ($p<0.01$). The concentrations of K^+, Ca^{2+}, Na^+, and Mg^{2+} in rainfall were 1.9, 0.8, 1.1, and 0.2 mg/L, respectively (Fig. 3). There were considerable variations in the concentrations of base cations after rainfall passed through the forest canopy. (Fig. 3) showed that except for Na^+, the concentrations of K^+, Ca^{2+}, and Mg^{2+} were more enriched in throughfall, stemflow, and surface runoff than in rainfall. In addition, base cations concentrations (K^+, Ca^{2+}, Mg^{2+}) in surface runoff were higher than those in throughfall and stemflow, with the exception that the Na^+ of stemflow in *C. carlesii* natural forest was higher than that in surface runoff.

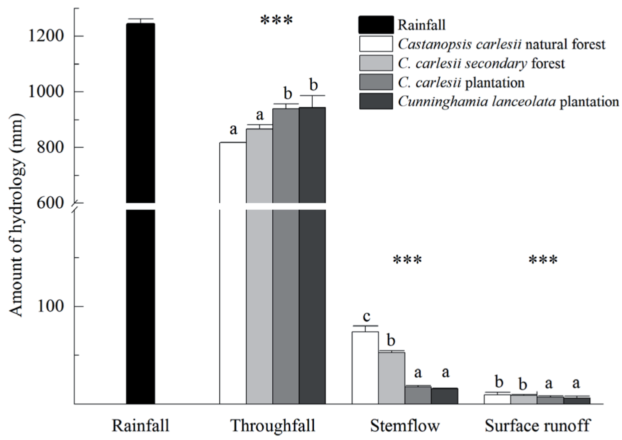

Fig. 1. The water amount of rainfall, throughfall, stemflow and surface runoff. Different lowercase letters indicate significant differences among forest types ($p<0.05$). Error bars represent the standard errors (n = 3). $^{***}p<0.01$.

Furthermore, there was a significant effect ($p<0.001$) of the forest types on base cations in throughfall, stemflow, and surface runoff. Among the four forest types, the concentration of base cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}) of throughfall and stemflow in *C. carlesii* plantation were lowest, and the concentrations of K^+, Ca^{2+}, and Na^+ of surface runoff in *C. carlesii* natural forest were lowest.

Fluxes of Base Cations and Importance of Influencing Factor for Throughfall

The annual fluxes of K^+, Ca^{2+}, Na^+, and Mg^{2+} in rainfall were 20.7, 8.3, 11.9, and 1.3 kg/ha/yr, respectively (Fig. 4). Because of the enrichment of the base cations in throughfall, the fluxes of K^+, Ca^{2+} and Mg^{2+} in throughfall were 2.9-4.2, 4.4-5.9, and 2.5-4.0 times of those in rainfall, respectively (Fig. 4). The throughfall flux of Ca^{2+}, and Mg^{2+} in *C. carlesii* plantation were significantly higher than those in the other forest types, while the flux of Na^+ in the four forest types did not differ significantly in throughfall. The fluxes of base cations in stemflow had a consistent pattern among the four forest types: *C. carlesii* natural forest >*C. carlesii* secondary forest >*C. carlesii* plantation >*Cun. lanceolata* plantation. The surface runoff fluxes of K^+, Ca^{2+}, and Na^+, in *C. carlesii* secondary forest were higher than those in the other forest types. The NTF can indicate the absorption and leaching of rainfall passing through the canopy, with K^+, Ca^{2+}, and Mg^{2+} showing leaching through the canopy (NTF were positive), while Na^+ was absorbed (NTF were negative) (Table 3).

Compared with stemflow and surface runoff, the base cations of throughfall had the largest contributions to forest floor. Therefore, we used random forest model to test the importance of different driving factors on the throughfall of base cations. The random forest model explained 51.6-86.6% of the variance of all factors for fluxes of base cations in throughfall. (Fig. 5) showed that rainfall duration and temperature (understory

Table 2. Water volume of throughfall, stemflow, and surface runoff for four forest types from April 2021 to March 2022. Values are means±standard errors.

Forest types	*Castanopsis carlesii* secondary forest	*C. carlesii* plantation	*Cunninghamia lanceolata* plantation	*C. carlesii* natural forest
Throughfall (mm)	867.1±15.0	940.7±16.1	943.9±42.3	818.0±1.2
Stemflow (mm)	53.2±1.5	17.8±1.1	16.1±0.2	74.6±5.5
Surface runoff (mm)	9.2±0.4	7.4±1.0	6.4±1.6	9.7±2.5

temperature and atmospheric temperature) were the dominant factors regulating the fluxes of throughfall, which had the most important effect on the fluxes of K^+, Ca^{2+}, Na^+, and Mg^{2+} in throughfall.

Discussion

Our results showed a clear difference of rainfall partitioning patterns and base cations redistribution patterns among four subtropical forest types. In this study, the concentrations of base cations in throughfall, stemflow, and surface runoff significantly increased after rainfall passed through the forest canopy, except for Na^+, which was more concentrated in rainfall and surface runoff (Fig. 3). Additionally, the NTF of base cations input to the four forests are notable different (except for K^+), which means forest floor in different forest types had different amount of receiving the nutrient of base cations by hydrological pathways (Table 3).

Different Rainfall Partitioning Patterns among Forest Types

We observed significant difference in rainfall partitioning patterns among the four forest types (Fig. 1), consisting with our hypothesis that forest transformation has an important effect on rainfall partitioning. The proportion of throughfall in rainfall is 65-75% among four forest types, which is consistent with the proportion observed in many other forest ecosystems [4, 7, 33]. Numerous studies have shown that in the process of rainfall partitioning, the formation of throughfall is influenced by meteorological conditions, canopy

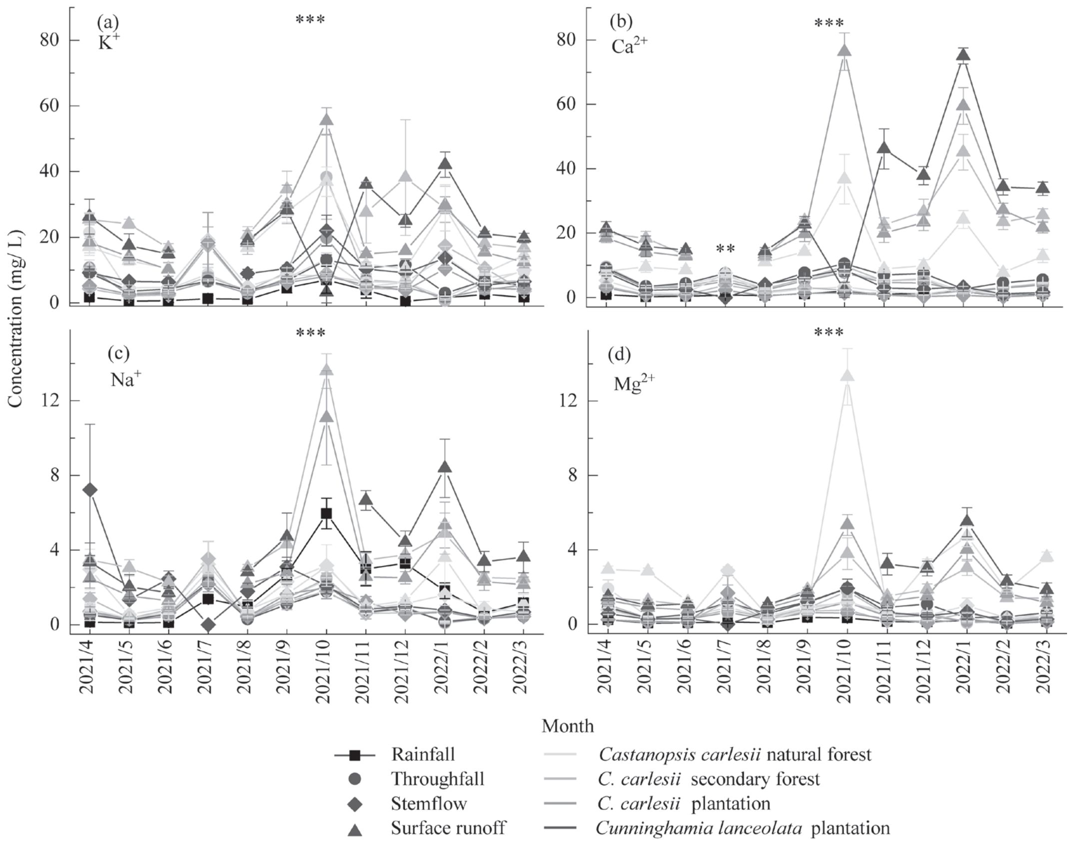

Fig. 2. The concentrations of K^+, Ca^{2+}, Na^+, and Mg^{2+} for rainfall, throughfall, stemflow, and surface runoff in the same month. Error bars represent the standard errors (n = 3) $^{*}p<0.05$, $^{**}p<0.01$ and $^{***}p<0.001$.

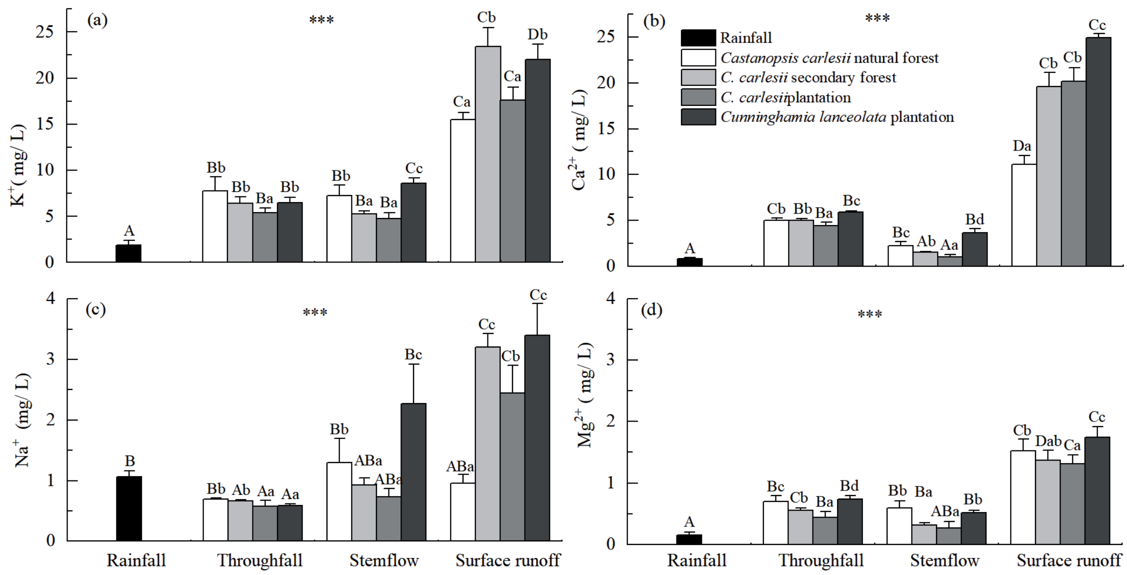

Fig. 3. The concentrations of K^+, Ca^{2+}, Na^+, and Mg^{2+} for rainfall, throughfall, stemflow, and surface runoff. Different capital letters indicate significant differences in rainfall, throughfall, stemflow and surface runoff. Different lowercase letters denote significant differences among forest types ($p<0.05$). Error bars represent the standard errors ($n = 3$). $^*p<0.05$, $^{**}p<0.01$ and $^{***}p<0.001$.

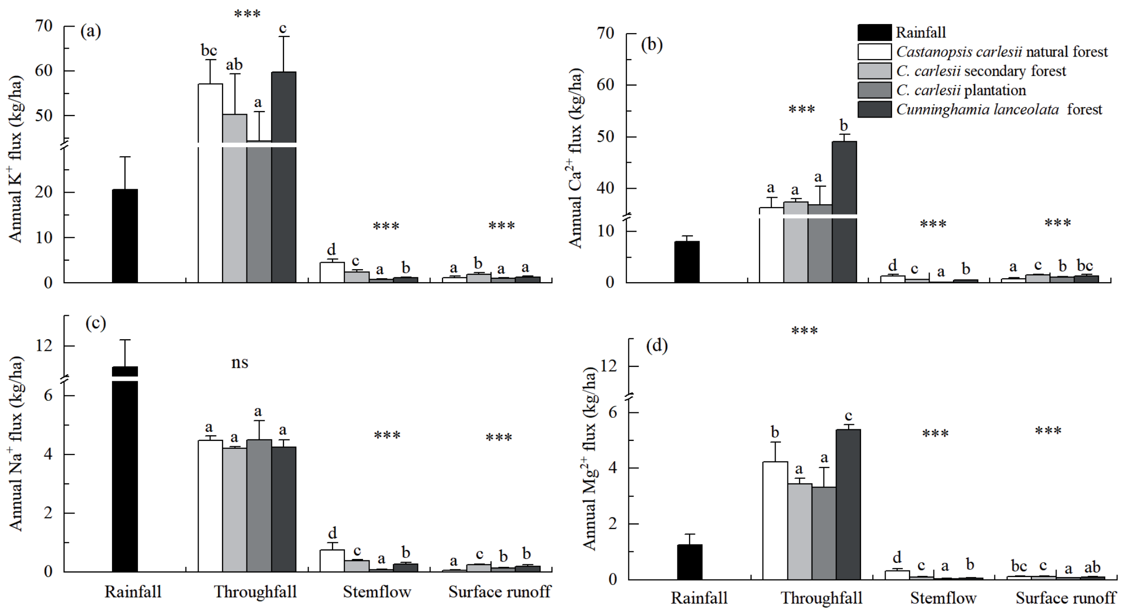

Fig. 4. The fluxes of K^+, Ca^{2+}, Na^+, and Mg^{2+} for rainfall, throughfall, stemflow, and surface runoff. Different lowercase letters indicate significant differences among forest types ($p<0.05$). Error bars represent the standard errors (n = 3). $^*p<0.05$, $^{**}p<0.01$ and $^{***}p<0.001$.

Table 3. The net throughfall fluxes (NTF) of K^+, Ca^{2+}, Na^+, and Mg^{2+} in the four forest types. CCN: *Castanopsis carlesii* natural forest, CCS: *Castanopsis carlesii* secondary forest, CCP: *Castanopsis carlesii* plantation, CLP: *Cunninghamia lanceolata* plantation. Different lowercase letters denote significant differences among forest types ($p<0.05$).

Forest type	K^+ (kg/ha)	Ca^{2+} (kg/ha)	Na^+ (kg/ha)	Mg^{2+} (kg/ha)
CCN	41.0 ^{a}	29.3 ^{a}	-6.7 ^{b}	3.2 ^{b}
CCS	31.9 ^{a}	29.7 ^{a}	-7.4 ^{a}	2.2 ^{a}
CCP	24.4 ^{a}	28.7 ^{a}	-7.3 ^{ab}	2.0 ^{a}
CLP	40.3 ^{a}	41.4 ^{b}	-7.4 ^{a}	4.1 ^{b}

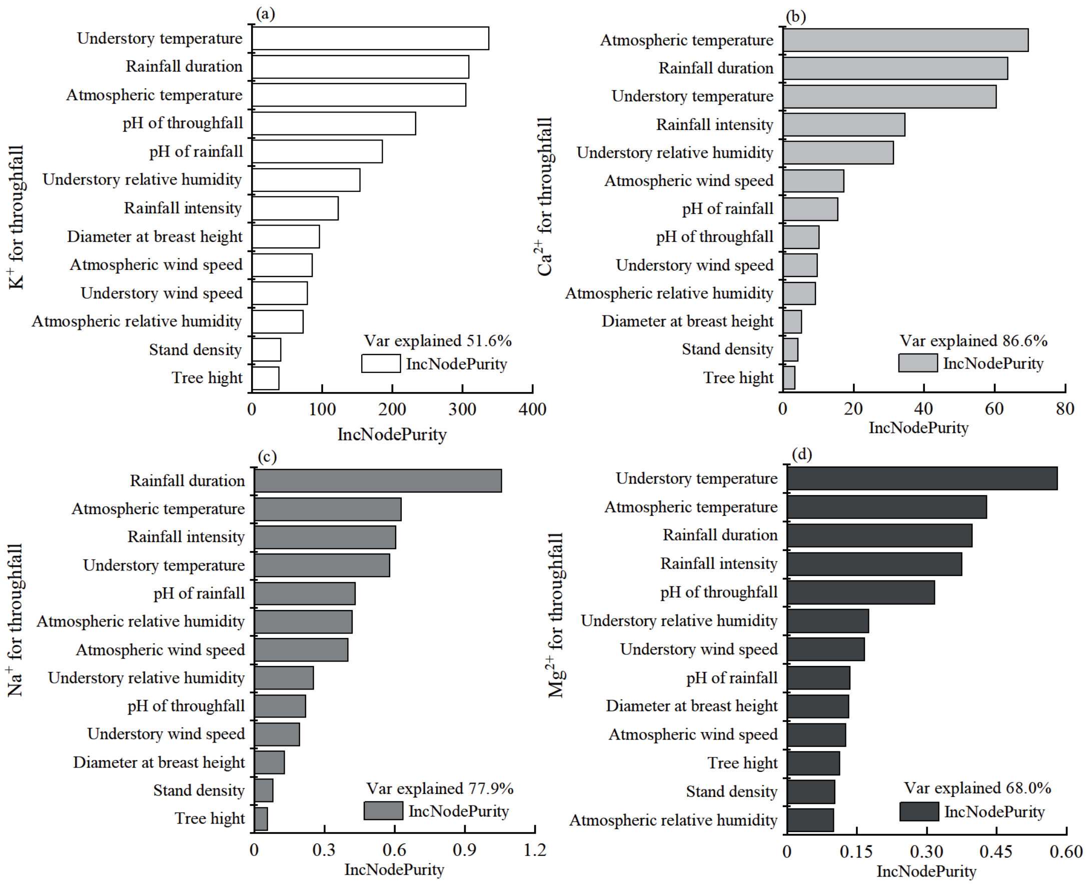

Fig. 5. The importance of the factors affecting the fluxes of base cations in throughfall was ranked by random forest model.

characteristics, and site characteristics [3, 34]. In our study, the amount of throughfall in *C. carlesii* plantation and *Cun. lanceolata* plantation was significantly higher than that in *C. carlesii* natural forest. With similar site characteristics and meteorological conditions, this difference may be attributed to the difference in forest characteristics. After forest transformation, the planting density of *C. carlesii* plantation and *Cun. lanceolata* plantation were sparser than that of *C. carlesii* natural forest, and the tree height was lower than that of *C. carlesii* natural forest (Table 1), so interception of both forests in the canopy layer might be weaker than that of *C. carlesii* natural forest**,** thus resulting the throughfall of *C. carlesii* plantation and *Cun. lanceolata* plantation were larger than *C. carlesii* natural forest**.** The formation of stemflow is mainly driven by plant characteristics, such as DBH, bark texture, plant height, and leaf types [3, 35]. So, it is unsurprising that the *C. carlesii* natural forest had the maximum stemflow, because it has the largest DBH, the highest tree height, and smooth bark texture among the four forest types. However, there is no distinct difference in the stemflow between *C. carlesii* plantation and *Cun. lanceolata* plantation. It may be that the DBH of *Cun. lanceolata* plantation is larger and the tree height is taller, thus offsetting the impact of the rough bark texture of trees.

Among the amount of surface runoff for the four forest types, the amount of *Cun. lanceolata* plantation and *C. carlesii* plantation were significantly smaller than *C. carlesii* secondary forest and *C. carlesii* natural forest (Fig. 1). The amount of litter and leaf type had a vital effect on the formation of surface runoff [17, 36-37]. Compared with the litter layer of coniferous species, the litter layer of broad-leaved species had a greater water storage capacity and formed a greater lateral flow in the litter layer, thus making it easier to form surface runoff [18]. However, the litter volume of *C. carlesii* plantation is far less than that of *C. carlesii* natural forest and *C. carlesii* secondary forest, so its surface runoff was smaller (Table 1).

Concentrations and Fluxes of Base Cations in Four Forest Types

The interaction between rainfall and forest canopy will cause a strong change in the chemical composition of rainfall after it passes through the canopy [38-39]. We also observed that the concentration of K^+, Ca^{2+}, and Mg^{2+} in stemflow and throughfall was 1.8-7.3 times higher than that in rainfall (Fig. 3). Vegetation surface can receive a large amount of dry deposition [31, 40], rainwater washes off the soluble matter that stays on the surface by flowing through the vegetation surface, thus promoting the enrichment of base cations in throughfall and stemflow [41-42]. K^+ is mostly present in plants as ions and has high mobility in cells near the leaf surface [43], making it more susceptible to leaching by throughfall and stemflow as it passes through the canopy [44-45]. Zeng et al. [46] noticed that the leaching amount of Ca^{2+} in the Shaoshan forest was very large, and it was the main ion buffering acid rain in the Shaoshan forest canopy. In addition, Du et al. [40] found that the forest canopy in China has captured a large amount of atmospheric base cation deposition, especially in the southern region. Based on those, we suggest that the high enrichment of calcium in the canopy was likely to be closely associated with the large deposition of atmospheric base cations in the forest and occasional acid rain (pH less than 5.6 in 11 out of 36 rainfall events). It is also noteworthy that because coniferous species can capture more dry deposition, while the bark of *Cun. lanceolata* plantation is rough and cracked, resulting in a longer contact time of rainfall in the trunk, which may be an important reason why the concentration of K^+, Ca^{2+}, and Na^+ in the stemflow of *Cun. lanceolata* plantation is significantly higher than that of the other three forest types [25-26, 38].

However, tree species have specific contributions to nutrients in throughfall and stemflow [4, 38, 41]. The leaching of Na^+ was observed to be weak in many forest ecosystems, and the flux of Na^+ in throughfall was comparable to that in rainfall [9, 41]. However, compared with rainfall, we observed lower Na^+ concentrations and fluxes in throughfall for four forest types, which indicated that Na^+ uptake was the dominant mechanism contributing during the canopy exchange process (Fig. 3 and Fig. 4). Na^+ plays an important role in the osmotic pressure of plant cells and also contributes to the growth and development of vegetation, but there is a threshold value for Na^+ uptake by plants [47]. The phenomenon of Na^+ uptake by the forest canopy here still needs further observation.

Additionally, we found that base cations were heavily enriched in surface runoff, and its enrichment was higher than that of throughfall and stemflow (Fig. 3). The litter layer plays an important role in delaying surface runoff, so rainfall stays in the litter layer for a long time [17, 36], which can fully leach nutrients released during litter decomposition [19, 49]. On the other hand, the abundant rainfall and warm temperature in subtropical regions are favorable to litter decomposition and nutrient cycling [48], which has a certain promotion effect on the enrichment of base cations in surface runoff. In addition, the large yield of litter on the sample plot also provides important material conditions for the enrichment of base cations in surface runoff (Table 1).

The time required to replenish nutrients to the soil through rainfall partitioning is much faster than the process of nutrient return by litter decomposition, so the nutrient fluxes generated by the rainfall partitioning is a fast channel for nutrient transport from canopy to forest floor [8, 49]. Although the concentrations of base cations in surface runoff and stemflow were higher than that in throughfall, the volume of throughfall was higher, which justifies the higher nutrient yields in throughfall (Fig. 4). On these grounds, we used the random forest model to estimate the influence of different factors on the base cations flux of throughfall. Among them, temperature and rainfall duration have relatively more important effects on fluxes of base cations in throughfall (Fig. 5). With a certain temperature range, the higher the temperature, the stronger the physiological activity of the vegetation [50], which may affect the base cations leaching in the canopy. Evaporation delays the saturation of canopy water storage capacity during high-intensity rainfall events, while the temperature is an important factor influencing evaporation and can therefore also affect the amount of throughfall [51]. In addition, rainfall duration affects the contact time between forest canopy and rainfall, and sufficient rainfall duration can make the interaction between canopy and rainfall more adequate and intense [33, 38]. There is a significant linear correlation between rainfall and throughfall [2, 4], while rainfall intensity and rainfall duration are closely related to rainfall amount, so rainfall intensity and rainfall duration can affect throughfall and its nutrient yield. In addition, the NTF represent the nutrient energy transferred from the canopy to the forest floor, and our study showed that the NTF of base cations delivered to the forest floor by the canopy of four forest types was different (Table 3). The NTF of K^+, Ca^{2+}, and Mg^{2+} from four forest canopy were greater than those ions fluxes in rainfall, while the NTF of Na^+ were less than rainfall flux. Among the four forest types, *C. carlesii* natural forest had the highest NTF of K^+ and Na^+, while *Cun. lanceolata* plantation had the highest NTF of Ca^{2+} and Mg^{2+}. It is noteworthy that the Ca^{2+} input to the forest floor from *Cun. lanceolata* plantation was significantly higher than that from other forest types, and the fluxes were larger, which was important for alleviating the acidic soil in this region.

The changes in rainfall partitioning by forest transformation are direct and continuous, but the effects on hydrological fluxes of base cations are indirect. Firstly, the planting after fire and clear-cutting resulted in apparent changes in canopy characteristics, planting density, and vegetation populations [30]. Canopy and vegetation cover had profound effects on rainfall partitioning in forest ecosystems [2, 52], so that the rainfall partitioning patterns would change after forest transformation. Secondly, the forest canopy, as the first interface between forest and rainfall, significantly affects the chemical composition of rainfall [53, 38]. Differences in forest canopy characteristics can significantly affect the base cations of canopy level transport to the forest floor [26], which resulted in the NTF being different in four forest types. Thirdly, forest transformation significantly altered soil properties and fertility [54-56], and Corti et al. [57] showed that soil properties also affect the chemical composition of stemflow and throughfall to some extent. In conclusion, forest transformation affects the transport of base cations during forest hydrology directly or indirectly in several ways.

Conclusions

In summary, forest transformation alters the stand characteristics of forest, which has a direct impact on the rainfall partitioning patterns of forest ecosystems, and this impact resulted in differences in the migration levels of base cations with rainfall partitioning for the four different subtropical forest types. Forest transformation caused obvious changes in stand characteristics, thus directly or indirectly influencing the vertical transport of base cation fluxes in several ways, such as tree species, planting density, bark morphology, DBH, and soil nutrient status. Compared with *C. carlesii* natural forest, the NTF of base cations of *C. carlesii* secondary forest and *C. carlesii* plantation was lower, but the NTF of Ca^{2+} and Mg^{2+} of *Cun. lanceolata* plantation was higher than that of *C. carlesii* natural forest. This evidence indicates that forest transformation has a negative impact on the amount of base cation circulation in zonal broad-leaved forests, but *Cun. lanceolata* plantation has more advantages in Ca^{2+} circulation.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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