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CHANGE OF NUTRIENT IMPORT AND EXPORT IN PROCESS OF RAINFALL IN AILAO MOUNTAIN OF YUNNAN PROVINCE[①]

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ABSTRACT: In this paper, the effects of rainfall on nutrient import and export in the broad-leaved evergreen forest in southwest Yunnan Province have been observed. The results show that in the process of rainfall the nutrient import in rainfall is mainly N and the major elements of nutrient import in throughrain are P, K and Mg. They occupy 69.85%, 77.33%, 98.19%, and 80.40% of the total nutrient import respectively. Ca occupies about half of the total nutrient import in rainfall and throughrain and the percentages are 45.35% and 54.38% respectively. The major form of nutrient export is soil percolation. N, P, K, Ca and Mg occupy 96.52%, 86.79%, 69.13%, 98.17% and 97.21% of the total nutrient export respectively. In nutrient cycle, N, P, K and Ca increase 25.94 kg/(ha. a), 0.353 kg/(ha. a), 3.83 kg/(ha. a), 1.26 kg/(ha. a) respectively, but Mg reduces 0.654 kg/(ha. a).
KEY WORDS: broad-leaved evergreen forest, rainfall, nutrient import and export, Ailao Mountain.

The change of nutrient import and export in the process of rainfall occupies a main part in forest ecosystem and also plays a very important role in nutrient circulation. We have done some research on this subject in Ailao Mountain Nature Reserve of Yunnan Province since 1991. We hope the results can show the change of nutrient import and export in the process of rainfall in subtropical broad-leaved evergreen forest of southwest China.

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I. NATURAL CONDITION AND GENERAL SITUATION OF THE RESEARCH AREA

The research area lies in the center of Ailao Nature Reserve——Xujiaba, Jingdong County, central south of Yunnan Province. It is one of the key nature reserves in China, borders Chuxiong City, 24°32′ north latitude, 101°01′ east longitude, 2,450 m above sea level. It belongs to damp mountain broad-leaved evergreen forest of subtropical zone. According to the meteorological data observed by Ailao Mountain Ecology Station, the annual average temperature, rainfall and humidity is 11.1 ℃, 1,860 mm, 86% respectively. The humidity is above 90% from June to January next year and 60%—70% in dry season. The total amount of solar radiation is 36.63×10^4 J/(cm. a), Accumulated temperature≥10 ℃ is 3,049.5 ℃. The average tempreture is 16.8 ℃ in the hotest month and 4.7 ℃ in the coldest month, the lowest temperature is −7 ℃. The stratum is mainly composed of ancient gneiss, crystalline schist, chlorite schist, crystalline silica. After many years of growth, these rocks changed into mountain yellow-brown earth[1].

Having a slope of 11° in a westward direction and covering an area of 50×50 m^2, the sampling area is closed to Ailao Mountain Ecology Station, with 124 trees. The type of the forest here is damp mountain broad-leaved evergreen forest. The height of upper arboruous layer is 20 m to 25 m, the age of trees is 40 a to 50 a and average coverage is 0.9. The height of lower arboruous layer is 5 m to 15 m, average coverage is 0.5. The arbor cover mainly consists of Fagaceae, Lauraceae, Theaceae and Mangnoliaceae. The shrub layer is composed of Sinarundinaria with an average coverage of 0.7 and a height of 1 m to 3 m. The height of herbaceous layer is lower than 0.5 m, average coverage is 0.3. The biomass of arboruous layer, shrub layer and herbaceous layer is 491.17 t/ha, 7.39 t/ha, 1.14 t/ha respectively.

II. METHOD OF RESEARCH

1. Measurement of Rainfall

Rainfall is observed both inside and outside the forest in Ailao Mountain Meteorolgic Observatory. Then the observation results are analysed, calculated, corrected and adjusted.

2. Measurement of Throughrain

In the sampling area, we put 7 rain gauges under the arboruous layer and observe 3 times a day regularly. After the rainfall there will be once more observation.

3. Measurement of Trunk Runoff

We choose 6 trees according to their diameters, fix one end of a PVC plastic on a trunk, then spiral one and a half circle and tighten it. The other end of the pipe is inserted in a plastic container, observe 3 times a day regularly, after a rainfall there will be one more observation.

4. Measurement of Surface Runoff

We make 2 runoff squares with PVC plastic plate, each covers an area of 2 m$\times$5 m. We collect runoff in a plastic container, observe 3 times a day regularly, after the rainfall there will be one more observation.

5. Measurement of Solute Percolation

Inset 40 cm$\times$40 cm$\times$5 cm PVC plastic water collection plate into soil horizontally with two replicates, percolation water flow through plastic tube to plastic container, check it three times a day, 4 times after rain.

6. Analysis of Nutrient Elements

N is measured by direct distillation, P by Molybdenum blue colorimetric method, and K, Ca, Mg by HITACHI—17030 Atomic Absorption Photometer.

III. RESULT OF RESEARCH

1. Nutrient Import

Nutrient elements are imported into forest system by rainfall which becomes the natural source of nutrient and leaches the secretion of trunks and crowns. Some of the elements participate in the chemical reaction of secretion. Now we can draw a conclusion that the plants absorb and adsorb part of the nutrient elements of rainfall, at the same time some of the nutrient elements are leached out and enter the soil system with throughrain and trunk runoff. So, besides rainfall, the import of nutrient elements also includes throughrain, trunk runoff. The results are shown in Table 1.

Table 1 The average annual amounts of nutrient import and export in the period from May 1991 to April 1993 (kg/ha. a)

		N	P	K	Ca	Mg
Nutrient import	Rainfall	14.179 69.85%	0.123 22.49%	0.080 1.33%	1.429 45.35%	0.183 19.08%
	Throughrain	6.099 30.04%	0.423 77.33%	5.925 98.19%	1.789 54.38%	0.772 80.40%
	Stemflow	0.022 0.11%	0.001 0.18%	0.029 0.48%	0.009 0.27%	0.005 0.52%
	Leaching	—	0.301 55.03%	5.864 97.34%	0.306 9.30%	0.593 61.84%
	Total amount	20.300 100%	0.547 100%	6.024 100%	3.290 100%	0.959 100%
Nutrient export	Soil percolationn	4.207 96.52%	0.046 86.79%	1.516 69.13%	1.989 98.17%	1.568 97.21%
	Surface runoff	0.152 3.48%	0.007 13.21%	0.677 30.87%	0.037 1.83%	0.045 2.79%
	Total amount	4.359 100%	0.053 100%	2.193 100%	2.026 100%	1.613 100%
Difference	Total import minus total export	15.941	0.535	3.831	1.264	−0.654

1.1 *Rainfall nutrient import*

The order of rainfall nutrient import is N>Ca>Mg>P>K, they occupy 69.85%, 45.35%, 19.08%, 22.49% and 1.33% of the total import respectively. Rainfall nutrient import is mainly N, then Ca.

1.2 *Throughrain nutrient import*

Throughrain is the most important nutrient import form. The order of nutrient import is N>K>Ca>Mg>P, they occupy 30.04%, 98.19%, 54.38%, 80.40% and 77.33% of the total import. It is clear that the import of K is mainly throughrain.

1.3 *The nutrient import of stemflow*

The nutrient import of trunk runoff obeys the order of K>N>Ca>Mg>P. They occupy 0.48%, 0.11%, 0.27%, 0.52% and 0.18% of the total import respectively.

1.4 *Leaching amount*

In view of leaching nutrient amount, except N, other elements are positive number. The leaching amount of K, Mg, Ca and P is 5.864 kg/(ha.a), 0.593 kg/(ha.a), 0.306 kg/(ha.a), 0.30 kg/(ha.a) respectively.

2. Nutrient Export

As the intensity of throughrain becomes stronger and soil water becomes saturate, the nutrient is adsorbed and fixed by rotten leaves, humus and soil colloid. On the other hand, the nutrient in rotten leaves, humus and soil colloid is leached out from water and loses in the process of surface runoff and soil percolation, which can be seen from Table 1.

2. 1 *Nutrient export of surface runoff*

The order of nutrient export of surface runoff is K>N>Mg>Ca>P. Occupies the most amount, 0. 677 kg/(ha. a). They Occupy 30. 87%, 3. 48%, 2. 76%, 1. 83% and 13. 21% of the total export respectively.

2. 2 *Nutrient export of soil percolation*

The order of nutrient export amount is N>Ca>Mg>K>P. They occupy 96. 52%, 98. 17%, 97. 21%, 69. 13% and 86. 79% of the total amount respectively. From Table 2, we can see nutrient export of soil percolation at different soil depths (varying from 10 cm, 25 cm, 45 cm to 65 cm). From top to bottom, the nutrient export amount reduces gradually. This shows that soil colloid adsorbs more and more nurtient from top to bottom, but soil nutrient leaching and the transport of nutrient by water weakens.

3. Nutrient Circulation during Rainfall

During the rainfall, the nutrient was imported through surface runoff and throughrain, then it is exported through surface runoff and soil percolationn. As for forest-soil system, from Table 1, we can see the amount of nutrient export and import, and the contribution of each elements to the system during the rainfall.

Table 2 The average annual export amount of nutrient percolationn at different soil depths in the period from May 1991 through April 1993 (kg/ha. a)

	N	P	K	Ca	Mg
Percolation export(10cm)	1. 43	0. 024	1. 41	0. 91	0. 84
Percolation export(25cm)	1. 39	0. 006	0. 03	0. 41	0. 34
Percolation export(45cm)	0. 58	0. 005	0. 05	0. 48	0. 25
Percolation export(65cm)	0. 54	0. 011	0. 03	0. 19	0. 13
Total nutrient export	4. 21	0. 046	1. 52	1. 99	1. 56

3. 1 *The increase of nutrient*

The nutrient elements which are increased in the forest-soil system are N, P, K, Ca, the amount is 15. 941 kg/(ha. a), 0. 533 kg/(ha. a), 3. 831 kg/(ha. a) and 1. 264 kg/(ha. a) respectively.

3. 2 *The decrease of nutrient*

The nutrient element which is decreased in the system is Mg, the amount is 0. 654 kg/(ha. a).

IV. ANALYSIS AND DISCUSSION

1. A Comparison of Import Nutrient Elements

K. A Amerson thinks that N and other elements change most during the rainfall, but in general it changes less in cold areas than in hot areas. The content may increase near industrial areas or fire, especially N[2]. Around coastal areas, Na, Ca and Mg may increase greatly. Yunnan is characterized by variety of mountains and changeable climate. We can not classify the climate type just from geographic locations. A great deal of materials show that N changes greatly during the rainfall in different areas. In Table 3, we can see the change in different areas. The content of N in Nigeria is 14. 01 kg/(ha. a), Canada 1. 4 kg/(ha. a), Germany 23. 9 kg/(ha. a), Guangzhou 3. 48 kg/(ha. a), Ailao Mountain 14. 18 kg/(ha. a). The change of N in rainfall in different areas has something to do with the climate, soil denitrification, the decomposition of organic matter, atmospheric dust, fuel and industrial pollution. The content of N is the highest in the rainfall of Ailao Mountain, because people use a lot of fertilizer and burn a lot of firewood around these areas. And also because of adsorption and absorption of total leaf areas of forest canopy and trunk surface, the content of N in throughrain and stemflow decreases accordingly. All these show that the import of N is mainly through rainfall.

The content of P in the rainfall is very low. The foreign material shows that the content is usually between 0. 0075—0. 225 kg/(ha. a). In Table 3 we can see that the contents of P in Nigeria, Canada, Germany, Guangzhou and Ailao Mountain are 0. 42 kg/(ha. a), 0. 23 kg/(ha. a), 0. 48 kg/(ha. a), 0. 04 kg/(ha. a), 0. 12 kg/(ha. a) respectively. In general, P in the rainfall is mainly from the dissolving of atmospheric dust. The leaching of plants is very difficult in the process of rainfall. The leaching amount of Ailao Mountain, Nigeria damp tropical forest, Canada Douglas fir forest, Guangzhou damp pine artificial forest is 0. 301 kg/(ha. a), 3. 68 kg/(ha. a), 2. 5 kg/(ha. a), 0. 008 kg/(ha. a) respectively. Some red earth areas are lacking in P. In those areas, the complement in P is mainly from rainfall and leaching of plants.

Table 3 A comparison of import and export in different regions (kg/(ha. a))

	N	P	K	Ca	Mg
Nigerian damp tropical forest (Nye, 1961)					
Rainfall import	14.01	0.42	17.4	12.67	11.32
Throughrain import	26.45	4.10	237.51	41.58	29.14
Leaching amount	12.44	3.68	220.11	28.91	17.82
Canadian Douglas fir forest (Abee & Lavender, 1972)					
Rainfall import	1.4	0.23	0.11	2.59	1.27
Throughrain import	3.35	2.74	21.72	2.09	2.12
Leaching amount	1.95	2.51	21.61	2.33	0.85
Export by brooks	0.38	0.52	0.25	50.32	12.44
European *Fagus longipetiolata* Seem (Fridrikson, 1972)					
Rainfall import	23.9	0.48	2.0	12.4	1.79
Export (go into ground water)	6.2	0.01	1.6	14.1	2.40
Guangzhou damp pine artificial forest (Tang Changyuan, 1992)					
Rainfall import	3.48	0.044	1.17	9.16	8.31
Throughrain import	6.01	0.048	3.08	14.49	9.21
Stemflow import	2.59	0.004	0.33	3.46	1.40
Leaching amount	5.12	0.008	2.24	8.78	2.29
Evergreen broad-leaved forest in Ailao Mountains of Yunnan					
Rainfall import	14.18	0.12	0.08	1.49	0.18
Throughrain import	6.10	0.42	5.92	1.79	0.77
Stemflow import	0.022	0.001	0.029	0.009	0.005
Leaching amount	—	0.301	5.87	0.31	0.59
Export (go into ground water)	4.36	0.053	2.19	2.03	1.62

K is an essentially important element for the growth of plants. Not much K is contained in rainfall, however, much nutrient could be produced when rain leaches plants. And this is quite significant for the supplement of K in soil. According to some foreign dada, the general content of K in rainfall is 0.9—15.8 kg/(ha.a). The contents of K in the rainfall in Nigeria, Canada, Germany and Guangzhou are generally 17.4 kg/(ha.a), 0.11 kg/(ha.a), 2.0

kg/(ha. a) and 1. 17 kg/(ha. a) respectively, while the content in Ailao Mountain is comparatively low (0. 08 kg/ha. a). For the high solubility of K, the content of K in throughrain by the leaching of rain is 5. 915 kg/(ha. a), which is increased comparing with rainfall. It is 74 times as much as that in the rainfall in Ailao Mountain.

The leaching amount in Ailao Mountain is 5. 87 kg/(ha. a), which is lower than that in Nigerian moist tropical forest (220. 11 kg/(ha. a)) and Canada Douglas fir forest (21. 61 kg/(ha. a)), while higher than that in Guangzhou damp pine artificial forest (2. 24 kg/(ha. a)).

Ca is mainly found in atmospheric dust or organism. Generally speaking, it is less contained and has slower speed of release and lower dissociation de gree in comparison with K . The content of Ca in the rainfall of this region is 1. 49 kg/(ha. a)), which is lower than that in Nigeria (12. 67 kg/(ha. a)), Germany (12. 4 kg/(ha. a)) and Guangzhou (9. 16 kg/(ha. a)), and is similar to that in Canada (2. 09 kg/(ha,a)). The leaching amount of Ca in the rainfall of Ailao Mountain is 0. 306 kg/(ha. a), which is distinctly lower than that in Nigerian moist tropical forest (28. 9 kg/(ha. a)), Guangzhou (8. 78 kg/(ha. a)) and Canadian Douglas fir forest(2. 33 kg/(ha. a)).

Mg is an element which is difficult to leaching. Mg in rainfall is originated when salt in oceanic monsoon are brought into inland and then dissolve in rainfall. Rainfall contains very little Mg. The content of Mg in rainfall in Nigeria, Canada, Germany, Guangzhou and Ailao Mountain are 11. 32 kg /(ha. a), 1. 27 kg/(ha. a), 1. 79 kg/(ha. a). 8. 31 kg/(ha. a) and 0. 18 kg/(ha. a) respectively. The leaching amount of Mg in this region is also lower than that in Nigerian moist tropical forest (17. 83 kg/(ha. a)) and Guangzhou damp pine artificial forest (2. 29 kg/(ha. a)), while it is similar to that of Canadian Gouglas fir forest (0. 85 kg/(ha. a)).

2. Comparison Between Export of Different Elements Nutrient

According to Table 3, export of N in Ailao Mountain is 4. 36 kg/(ha. a), which is 11 times higher than that in Canada (0. 38 kg/(ha. a)), while 1. 84 kg/(ha. a) lower than that is Germany (6. 2 kg/(ha. a)). Export of P is 0. 053 kg/(ha. a), 10 times lower and 5.times higher than that of Canada (0. 52 kg/(ha. a)) and Germany (0. 01 kg/(ha. a)) respectively. Export of K is 2. 19 kg/(ha. a), 8. 5 times higher than that in Canada (0. 25 kg/(ha. a)), and 0. 59 kg/(ha. a) higher than that in Germany. Export of Ca is 2. 03 kg/(ha. a), 25 times lower than that in Canada (50. 32 kg/(ha. a)) and 0. 78 kg/(ha. a) lower than that of Germany. Export of Mg is also lower than that in Canada (12. 44

kg/(ha. a)) and Germany (2. 40 kg/(ha. a)).

The differences of nutrient export is obviously resulted from the diversity of regions, soil circumstances, vegetation types and weather conditions.

3. Comparison Between Nutrient Exports of Rainfall, Throughrain and Stemflow

According to Table 1 the percentages of all kinds of nutrient import in the total amount of import display the contributions of three forms of nutrient imports to the forest-soil system.

They are displayed as follows:

N: rainfall (69. 85%)>throughrain (30. 04%)>stemflow(0. 11%)

P: throughrain (77. 33%)>rainfall (22. 49%)> stemflow(0. 18%)

K: throughrain (98. 19%)> rainfall(1. 33%)>stemflow(0. 48%)

Ca: throughrain (54. 38%)> rainfall (45. 35%)>stemflow(0. 27%)

Mg: throughrain (80. 40%)> rainfall (19. 08%)>stemflow(0. 52%)

Obviously, N is mainly found in the rainfall import while other elements as P, K, Mg in throuthrain import. Rainfall and throughrain bring much the same amount of Ca, each contains some half.

Since there is so little stemflow, which is 0. 227% of rainfall outside the forest, each element from stemflow counts for less than 1% of the total amount of nutrient import. Tang Changyuan and Wan Yi considered that, in the view of water cycling, rainfall inside forest and forest circumstances form area source, while the water is entering the woods in the form of point source, which is caused by stemflow and the space around roots[3]. For the broad-leaved evergreen forest in Ailao Mountain, nutrient is mainly imported in form of area source.

4. Nutrient Leaching by Rainfall

In Feng Zongwei's opinion[4], the increase of nutrient content in throughrain is from the rising liquid of cell wall. The protoplasm only absorbs some nutrient elements needed from the rising liquid while other nutrient gathers in cell wall and corneous layer. The nutrient elements were exchanged by H when it rains. The nutrient leached out can be dissolved by water, so it can be absorbed by plants directly without any complex dicomposition. At the same time nutrient leaching by rainfall speeds up the circulation of nutrient, and guarantees the needs of nutrient by plants. We draw a conclusion that leaching of forest crown by rainfall is very important in promoting the growth of plants.

When rainfall leaches crown and nutrients contained in plant exudate, the content of nutrient in throughrain and stemflow increases (according to Table 4). The nutrient in rainfall, throughrain and stemflow are arranged respectively as follows: N>Ca>Mg>P>K, N>K>Ca>Mg>P, and K>N>Ca>P>Mg. Now it is clear that in the three forms of nutrient import, apart from N, other nutrient contents increase by leaching. The contents are arranged as follows: stemflow>throughrain>rainfall. It well illustrates that leaching is quite important for the increase of nutrient import so as to supplement nutrient needed for the growth of plants.

Table 4 The average monthly concentration of nutrient materials in rainfall, throughrain and stemflow in the period from May 1992 to April 1993 (mg/L)

	N	P	K	Ca	Mg
Rainfall	5.257	0.059	0.029	0.466	0.064
Throughrain	3.154	0.167	2.357	0.674	0.328
Stemflow	4.456	0.178	5.419	1.712	0.906

V. CONCLUSION

1) Rainfall and throughrain are both mainly forms of nutrient import, while nutrient import by throughrain is more important. The nutrient import by stemflow is too little to be mentioned. The amount of import of N, P, K, Ca, Mg are 6.1 kg/(ha.a), 0.423 kg/(ha.a), 5.915 kg/(ha.a), 1.79 kg/(ha.a) and 0.77 kg/(ha.a) respectively in throughrain, and 14.18 kg/(ha.a), 0.123 kg/(ha.a), 0.08 kg/(ha.a), 1.49 kg/(ha.a) and 0.18 kg/(ha.a) respectively in rainfall.

2) Soil percolation is a main form of nutrient export, while export by ground runoff is the other. The export amounts of N, P, K, Ca and Mg are 4.207 kg/(ha.a), 0.046 kg/(ha.a), 1.516 kg/(ha.a), 1.989 kg/(ha.a) and 1.568 kg/(ha.a)in soil percolation respectively, while in the form of ground runoff, they are 0.152 kg/(ha.a), 0.007 kg/(ha.a), 0.677 kg/(ha.a), 0.37 kg/(ha.a) and 0.045 kg/(ha.a) respectively.

3) In forest-soil system, the import amount of nutrient circulation in rainfall is more than the export amount, or the element contents of N, P, K, Ca in the system increase, the increase amount is 15.94 kg/(ha.a), 0.535 kg/(ha.a), 3.81 kg/(ha.a) and 1.264 kg/(ha.a) respectively. In the system, Mg is the only nutrient which decreases by 0.654 kg/(ha.a).

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