[Article ID] 1003- 6326(2002)03- 0549- 06

Dynamics of pH value and metal elements of rainfall within mixed forests in Japanese pine and cypress①

LIU Yun-guo(刘云国)[1], ZENG Guang-ming(曾光明)[1], Y. Katayama[2], K. Nishimura[2], A. Nakanishi[2], H. Okazaki[2], T. Anzai[2], Li Xin(李 欣)[1], G. Iwazubo[2]

(1. Department of Environmental Science & Engineering, Hunan University, Changsha 410082, China;
2. Department of Agriculture, Kyoto University, Kyoto, Japan)

[Abstract] The dynamics of forest ecology was studied. The pH values, electrical conductivities and concentrations of metal and nonmetal elements in rainfall, stream, through-fall and stream flow were investigated based on the data collected from a small mixed forest watershed of Pinus densifora sieb et Zucc, *Pinus thunbergii* Parh and *Chamaecypari sobtusa* sieb et Zucc ex Endl at Kiryu nature reserve and a small barren watershed at Jakujo nature reserve, Ootsu, Shiga, Japan. The results show that both the mixed forest ecosystems of pine and cypress and the soil draw from granite affect the pH values and metal elements of rainfall. And the contribution of the mixed forest is greater than that of the barren. Moreover, the amount of input of most elements is larger than that of output in the ecosystem, which shows the elemental accumulation in the related forest ecosystem.

[Key words] mixed forest; small watershed; small barren watershed; pH value; metal elements

[CLC number] X 173 **[Document code]** A

1 INTRODUCTION

The challenge of forest ecosystems associated with the principle of sustainable development has been of concern to many researchers and managers in the last decade[1~3]. It requires not only the reinforcement of established principles and technologies but also their extension to much wider, higher and freer scope for the realization of sustainability for forest ecosystem management[4~6]. Compared with the studies on dynamics of nutritious elements in forest ecology and water pollution ecology, it is more lately developed to investigate the dynamics of pH value and metal elements of rainfall within forest ecology system[7, 8]. The study of the dynamics of pH value and metal elements of rainfall within forest ecology system is very important to the sustainability for forest ecosystem[9, 10]. Recently, a few scholars conducted some studies[9~11], but the utilization of forest ecosystem positioning station for carrying out perpetually research is still seldom. This paper is to report some of our researches related in this field, which will be much useful to the sustainable development of the forest ecosystem.

2 EXPERIMENTAL

2.1 Position studied outline

2.1.1 Kiryu position studied

Kiryu, altitude 190~ 255 m and watershed area 5.59 km^2, lies in the southeast of Shiga County, Japan. The soil mother substance of Kiryu is granite. Whole watershed is mixed forest with *Pinus desifora*, *Pinus thunbergii* and *Chamaecypari sobtusa*. The degree of closeness is nearly 1.0.

2.1.2 Jakujo position studied

Jakujo, altitude 375~ 430 m and watershed area 2.89 km^2, lies in the southwest of Kiryu (about 5 km away from Kiryu). The soil mother substance is granite. There are a few pines in water-collecting area, but they are badly grown. The degree of closeness is less than 0.1. The other conditions of Jakujo are similar to that of Kiryu besides the forest of them.

2.2 Sample collection

2.2.1 Sampling in Kiryu

1) Precipitation (P): Placed a polythene funnel with a diameter of 30cm in blank area out forest to collect rainfall, and then marked it with P.

2) Stream (S): Built a dam in water-collecting area to collect outflow water, and then marked it with S.

3) Through fall (TF): Placed two sets of collecting devices to collect rainfall in forest. While sampling, fully mixed two samples, and then marked it with TF.

4) Stream flow (SF): Coiled two PVC thin boards at the height of 1.5 m on the Japanese pine and cypress to collect stream flow. While sampling,

① **[Foundation item]** Project (70171055, 50179011) supported by the National Natural Science Foundation of China; project supported by the Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutes in 2000

[Received date] 2001- 10- 19; **[Accepted date]** 2002- 01- 24

fully mixed two samples, and then respectively marked with SFA and SFH.

2.2.2 Sample collected in Jakujo

1) Jakujo precipitation (JP): Sampled in the same way as 1) of 2.2.1, and then marked it with JP.

2) Jakujo stream (JS): Sampled in the same way as 2) of 2.2.1, and then marked it with JS.

2.2.3 Time

Frequency of collecting sample is once two weeks generally.

2.3 Analytical method

2.3.1 pH value measurement

After filtering water samples with a diameter 0.45 μm fibrous film, measure its pH value with the pH instrument.

2.3.2 Electrical conductivity measurement

Use electrical conductivity instrument to determine electrical conductivity.

2.3.3 ICP analysis

The contents of the elements, such as Ca, Mg, Al, Mn, Zn, Ba, Sr, Cu, V, Cr, Ni, Fe, B and Si, were determined with ICP (Induction Coupled Argon Plasma Spectrophotometer) instrument.

2.3.4 FE analysis

Use FE (Flame Emission) instrument to determine concentration of potassium.

2.3.5 INAA analysis

Use INAA (Instrumental Neutron Activation Analysis) to determine concentration of sodium.

3 RESULTS AND DISCUSSION

3.1 Dynamics of pH value

3.1.1 pH value and electrical conductivity of rainfall and outflow water

The pH value of rainfall directly affects the structure, function and system balance of forest ecosystem as well as forest environment. And the pH value of outflow water greatly affects ecological environment of lower reaches of rivers and all sorts of biomes, especially serious to biomes of water. The pH values of samples from Kiryu and Jkujo are showed in Table 1. The conclusion from Table 1 is that during the course of rainfall flowing through mixed forests of pine and cypress, the pH values change from high level to low level in the sequence of stream, precipitation, through fall and stem flow. The average pH value of P is 5.07, acid. The average pH value of S is 6.64. It almost belongs to neutrality and the adding amplitude is 1.57. This shows that forests greatly affect pH value of rainfall.

The average pH value of JP is 5.14 and that of JS is 6.55. The tendency is also from acid to neutrality. The adding amplitude is 1.41.

The increase of pH value results from ion exchange, complexation, precipitation, absorption and buffer in forest soil. Although pH value of precipitation at Kiryu is lower than that of Jakujo, its pH value of stream is higher than that of Jakujo. This showed that the pH value was affected more in mixed forests of Japanese pine and cypress ecosystems than in barren hill.

Table 1 Variation ranges and average of pH value and electrical conductivity of water samples at Kiryu and Jakujo

Water sample	pH			Conductivity/(μS·m^{-1})		
	Min.	Max	Av.	Min.	Max	Av.
P	4.35	5.80	5.07	3.96	55.20	14.54
JP	4.30	6.73	5.14	3.50	41.20	15.85
TF	4.06	5.90	4.84	7.55	100.0	48.60
SFA	4.04	6.37	4.86	6.14	147.0	68.64
SFH	3.14	6.46	3.78	13.80	473.0	160.1
S	6.18	6.97	6.64	30.00	40.10	37.23
JS	6.06	6.97	6.55	16.00	25.40	22.54
Times of sampling	28			30		

3.1.2 Relation of pH value of stream, precipitation, through fall, stem flow at Kiryu mixed forests

It is showed in Table 1 that the average pH value of TF is 4.84 and that of SFA is 4.86. The average pH value of SFH is 3.78, which is lower than that of P and TF. All of them are acidulated.

Some of rainfall at forests was evaporated. At the same time, the ion exchange happened. After rainfall was evaporated and enriched, the concentration of H^+ rose. This is the major reason that the pH values of TF and SF were reduced. On the other hand, the process of evaporation of backwater and the exchange of ion were changed with the tree species. This leads to the different pH value of SF in dissimilar trees species.

Connection analysis was conducted in order to study the relation of each analysis water sample. Regarding pH value as prefactor, marked with $X_0^{(0)}$, $X_0^{(0)}=\{X_0^{(0)}(j)\}$, $(j=1, 2, 3, 4, \cdots, 27)$, regarding pH value of P, TF, SFA and SFH as subfactor, marked with $X_{01}^{(0)}$, $X_{02}^{(0)}$, $X_{03}^{(0)}$, $X_{04}^{(0)}$, $X_{0i}^{(0)}=\{X_{0i}^{(0)}(j)\}$, $(i=1, 2, 3, 4, j=1, 2, \cdots, 27)$. After non-dimension dealing with, use formula:

$$\xi_{0i}=\xi_{0i}(j)=\frac{\min\min|X_0^{(0)}(j)-X_{0i}^{(0)}(j)|+0.5_x|X_0^{(0)}(j)-X_{0i}^{(0)}(j)|}{|X_0^{(0)}(j)-X_{0i}^{(0)}(j)|+0.5|X_0^{(0)}(j)-X_{0i}^{(0)}(j)|}$$

to analyze relation coefficient ξ_{0i} $(i=1, 2, 3, 4)$.

Classify each relation coefficient of prefactors and subfactors. Analyze relevant level with formula $r_{0i} = \sum_{i=1}^{n} \xi_{0i}(j)$. In this formula, r_{0i} ($i = 1, 2, 3, 4$) classify each relation coefficient of prefactors and subfactors. Then calculate gradually, and get relation coefficient series R.

$$R = \{r_{01} \quad r_{02} \quad r_{03} \quad r_{04}\} = \{0.78 \quad 0.77 \quad 0.74 \quad 0.71\}$$

Relation analysis indicated that relation level of S with P is the largest, that of S with SFH is the lowest, and those of S with TF and SFA are moderate. The conclusion shows that there is little effect between ecosystem of mixed forest of pine and cypress with pH value of rainfall, and ion exchange, chelae, sedimentation, absorption, amortization, etc, have more effect.

3.1.3 Electrical conductivity of water samples in Kiryu and Jakujo

Electrical conductivity of solution has close relation with ion concentration of solution. With ion concentration of solution increasing, electrical conductivity increases. Electrical conductivity of water samples in Kiryu and Jakujo is showed in Table 1.

Table 1 shows that average electrical conductivity of P Kiryu is 14.54 μS/m, and that of S is 37.23 μS/m. During the proceeding of inflow and outflow, average electrical conductivity increase is 156.05%. It shows that the ion concentration of solution is increasing during this proceeding. But pH value of outflow does not decrease. It can be proved that in the course of flow, ion concentration increases, but H^+ concentration doesn't increase.

Average electrical conductivity value of TF, SFA, and SFH is 48.60, 68.64, 160.12 μS/m. They are larger than that of P and S. But pH value is reversed. This shows that after rainfall has been dammed and evaporated H^+ and other ion are concentrated at crown of trees.

It can be seen from Table 1 that the average electrical conductivity of Jakujo rainfall is 15.85 μS/m and that of JS is 22.54 μS/m. During the proceeding of inflow and outflow, the average electrical conductivity increase is 42.21%. The increased level is less than that in Kiryu. It makes out that ion exchange at soil draw from granite is less than that at forests.

The main reason of electrical conductivity increase is that the increase of K^+ and Na^+ concentration in outflow.

3.2 Dynamics of metal elements of rainfall

3.2.1 Absorption principle

There is a potential difference of cell membrane between inside and outside, and the value range is 50 ~ 100 mV, so protein of cell in root of trees can transport metal ion of soil solution to cell at roots. Besides that, plant can absorb metal ion through leaves.

3.2.2 Dynamics of metal elements at mixed forests ecosystem in pines and cypress

In forests ecosystem, water is an important ecological factor. Rainfall at forests passes through crown of trees, trunk of trees first. Then it reaches to the woodland and forms flow of surface water and flow of groundwater. Lastly it flows into streams and then flows out of this watershed. For this reason, the amount and quality of stream water is very important. All metal concentration of water at Kiryu and Jakujo is showed in Table 2.

Based on Table 2, concentration of B, Si and other metal elements in TF, SFA and SFH is larger than that of P. It means that concentration of major elements in TF, SFA and SFH increases after rainfall flows into this forest ecosystem. This is because of dust at truck, branch and leaf being washed down. The elements of tree organs are dissolved and removed. And rainfall is condensed at crown of tree. Variance analysis and multi-comparison Q-test (deal source data according to logarithm) show that variance of metal elements concentration of TF and SFA in mixed forests system and that of P and SFH are remarkable. This shows that mixed forest ecosystem has greater effect on metal elements in rainfall. The test results are showed in Table 3 and 4.

Except Si, K and Na, the average concentration value of metal elements and B in outflow are lower than that of precipitation. The average concentration decreases are Zn 98.65%, Ni 100%, Mn 99.95%, Fe 90.85%, Cr 100%, Mg 41.81%, V 100%, Cu 95.60%, Al 95.42%, Sr 33.97%, Ca 24.51%, Ba 94.59%, B 94.59%. Except Mg, Sr, Ca, the others excess 95%. The average value is 82.08%. Variation analysis and multi-comparison Q-test show that the variance of metal elemental concentration of stream in mixed forests system and that of P are remarkable. This proves that mixed forests have great effect on metal elements in stream. The test result is showed in Table 5 and 6.

From the point of view on the clarification, if an elemental concentration at outflow of a forest watershed is lower than that of rainfall, it can be reckoned that forest has clarification function to this element. Analysis suggested that above-mentioned elements in stream at Kiryu is lower than that of rainfall and a conclusion can be reached that mixed forests at Kiryu have clarification function for those elements. The major reason about this is absorption of roots system, adsorption and exchange of soil.

3.2.3 Dynamics of metal elements at small barren watershed

Based on Table 2, except B, Si, Na and Al in stream, average values of other elements are lower

Table 2 Elements concentration of water samples at Kiryu and Jakujo (10^{-9})

Water sample		Zn	Ni	Mn	Fe	Cr	Mg	V	Cu
P	Min.	0	0	0.97	0	0	0	0	0
	Max.	20.20	52.34	53.23	50.86	151.49	180.68	72.59	80.80
	Av.	5.16	6.01	18.83	5.90	16.72	69.79	8.73	10.01
JP	Min.	0.21	0	0.40	0	0	2.73	0	0
	Max.	15.74	0.06	8.24	0.77	0	114.34	0	0.58
	Av.	3.94	0.004	3.75	0.07	0	32.90	0	0.10
S	Min.	0	0	0	0	0	37.29	0	0
	Max.	0.69	0	0.07	1.44	0	43.70	0	1.00
	Av.	0.07	0	0.01	0.54	0	40.61	0	0.44
JS	Min.	0	0	0	0	90	10.44	0	0
	Max.	0.21	0	0.42	0	0	23.14	0	0
	Av.	0.06	0	0.05	0	0	18.43	0	0
TF	Min.	1.38	0	15.54	0.26	0	18.79	0	0
	Max.	132.28	13.55	1 126.41	52.50	13.41	2 020.3	13.96	29.60
	Av.	30.97	3.55	279.44	14.27	3.13	533.59	3.02	11.86
SFA	Min.	0	0	0	0	0	0	0	0
	Max.	87.53	507.27	814.64	111.85	0.17	2 307.5	1.38	70.00
	Av.	23.21	37.08	221.76	33.93	0.01	536.31	0.14	19.07
SFH	Min.	0.31	0	0	1.23	0	4.81	0	0
	Max.	17.81	2.59	134.11	45.58	2.29	278.23	2.30	7.87
	Av.	5.20	0.33	38.28	13.31	0.19	97.39	0.19	0.81

Water sample		Al	Sr	Ca	Ba	K	Na	B	Si
P	Min.	0	0	0	0	79.33	91.14	0	0
	Max.	379.57	6.09	451.10	20.07	1 441.4	2 185.1	65.13	269.86
	Av.	50.65	1.56	175.06	2.63	406.14	687.29	10.91	46.79
JP	Min.	0	0.08	9.75	0	8.59	0	0	1.59
	Max.	6.33	2.17	330.24	0.81	618.85	2 231.8	0.69	86.50
	Av.	0.95	0.71	113.34	0.13	136.57	655.29	0.21	20.32
S	Min.	0.54	0.93	113.51	0.16	566.53	4 104.2	0.30	629.84
	Max.	3.89	1.12	150.25	0.26	770.02	8 812.1	1.33	892.98
	Av.	2.32	1.03	132.16	0.22	668.02	5 847.9	0.59	809.69
JS	Min.	0	0.25	29.25	0	230.87	886.00	0	388.83
	Max.	2.58	0.54	73.80	0.06	384.08	2 985.0	0.48	713.49
	Av.	1.11	0.39	52.29	0.02	294.26	1 826.7	0.25	598.38
TF	Min.	2.88	0.92	87.59	0.41	467.10	460.43	0	3.45
	Max.	372.92	67.45	6 735.3	44.00	12 151	6 006.2	34.96	319.67
	Av.	105.22	16.77	1 428.0	9.44	3 645.8	1 723.0	13.16	110.13
SFA	Min.	0	0	0	0	1 270.0	23.40	0	0
	Max.	307.68	64.97	5 828.6	34.02	12 419	5 484.8	43.97	342.23
	Av.	106.10	21.48	1 801.9	10.65	4 978.3	1 756.00	16.05	180.68
SFH	Min.	0	0	0	0	314.20	510.32	0.90	0
	Max.	64.79	10.50	1 016.6	6.32	4 537.6	8 791.3	10.00	718.53
	Av.	21.70	3.34	355.40	1.97	1 918.2	2 708.7	3.58	85.68

Table 3 Variance analysis of rainfall, through fall and stream flow at Kiryu

Factor	Degree of freedom	Difference square sum	Mean square	F value	F critical value, $F_{0.05}$	Test result	Remark
A	3	3.696 46	1.232 15	7.09*	2.81	Remarkable variance	Level of A is 4
B	15	51.474 31	3.431 62	19.74*	1.89	Remarkable variance	Level of B is 16
Surplus	45	7.821 06	0.173 80				
Total	63	66.991 82					

Table 4 Difference of average value of rainfall, through fall and stream flow (SFA and SFH) at Kiryu

Average at difference levels	XJ~ X_4	XJ~ X_1	XJ~ X_2	XJ~ X_3
X_3= 1.805	0.510*	0.506*	0.058	
X_2= 1.746	0.451*	0.448*		
X_1= 1.298	0.003			
X_4= 1.295				
Q value of factor A = 3.74, D= 0.389 796 8				

Table 5 Variance analysis of rainfall and stream at Kiryu

Factor	Degree of freedom	Difference square sum	Mean square	F value	F critical value, $F_{0.05}$	Test result	Remark
A	1	1.640 77	1.640 77	4.97*	4.54	Remarkable variance	Level of A is 2
B	15	25.084 01	1.672 27	5.07*	2.40	Remarkable variance	Level of B is 16
Surplus	15	4.952 29	0.330 15				
Total	31	31.677 06					

Table 6 Difference of average value of rainfall and stream at Kiryu

Average at different level	XJ~ X_2	XJ~ X_1
X_1= 1.298	0.453*	
X_2= 0.845		
Q value of factor A = 2.89, D= 0.415 140 5		

than that of rainfall. The average decreases are Zn 98.48%, Ni 100.00%, Mn 98.67%, Fe 100%, Mg 43.98%, Cu 100%, Sr 45.07%, Ca 53.86%, Ba 84.62%. The average value is 80.52% (because concentration of Cr and V is zero, there are decrease in Cr and V). Variation analysis and multi-comparison Q-test show it is not remarkable of variance between the concentration of stream metal elements and that of rainfall. This proves that barren hill has not great effect on metal elements in stream. The test result is showed in Table 7 and 8.

3.2.4 Input and output of system

The substance that flows into the system from the accompaniment of rain is the input. The substance that flows out of the system from the accompaniment of stream is output. The input and output of elements at Kiryu and Jakujo are showed in Table 9.

Table 9 shows that at mixed forests small watershed of Kiryu, except K, Na, Si, output of other elements are lower than input and there is a cumulating current. At barren small watershed of Jakujo, except K, Na, Si, B, Al, output of other elements are lower than input and there is a cumulating current. Concentrations of K, Na, and Si in stream are larger than that of rainfall. It is because the parent substance is granite.

4 CONCLUSIONS

1) During the course of inflow and outflow, pH values of TF, SFA and SFH at mixed forests small watershed of Kiryu increase. The average value is 1.57. At small barren watershed of Jakujo, pH value of JS increases, too. The average value is 1.41 and lower than that of mixed forests watershed.

2) At mixed forests ecosystem of pine and cypress, the concentrations of metal elements and other substance of TF, SFA and SFH increase currently. But those of S decreases currently. It is remarkable that the system affects TF, SFA and S. At small barren watershed, the concentrations of metal elements and other substance of JS decrease. But the influence is not remarkable.

Table 7 Variance analysis of rainfall and stream at Jakujo

Factor	Degree of freedom	Difference square sum	Mean square	F value	F critical value, $F_{0.05}$	Test result	Remark
A	1	0.000 10	0.000 10	0	4.54	Without remarkable variance	Level of A is 2
B	15	27.697 40	1.846 49	17.74*	2.40	Without remarkable variance	Level of B is 16
Surplus	15	1.561 24	0.104 08				
Total	31	29.258 74					

Table 8 Difference of average value of rainfall and stream at Jakujo

Average at different level	XJ~ X_2	XJ~ X_1
X_1 = 0.759	0.011	
X_2 = 0.748		
Q value of factor A = 2.89, D = 0.758 190 2		

Table 9 Input and output of elements at Kiryu and Jakujo (10^{-9})

Element	Kiryu			Kakujo		
	Input	Output	Difference	Input	Output	Difference
Zn	5.19	0.07	5.12	3.94	0.06	3.84
Ni	6.01	0	6.01	0.004	0	0.004
Mn	18.83	0.01	18.82	3.75	0.05	3.70
Fe	5.90	0.54	5.36	0.07	0	0.07
Cr	16.73	0	16.73	0	0	0
Mg	69.79	40.61	29.18	32.90	18.43	14.47
V	8.73	0	8.73	0	0	0
Cu	10.01	0.44	9.57	0.10	0	0.10
Sr	1.56	1.03	0.53	0.71	0.39	0.32
Al	50.56	2.32	48.33	0.95	1.11	−0.16
Ca	175.06	132.16	42.90	113.34	52.29	61.05
Ba	2.63	0.22	2.41	0.13	0.02	0.11
K	406.1	668.0	−261.9	136.6	294.3	−157.7
Na	687.3	5 847	−5160	655.3	1 826	−1 171
B	10.91	0.59	10.32	0.21	0.25	−0.04
Si	46.79	809.69	−762.9	20.32	598.4	−578.1

3) Mixed forests ecosystem of pine and cypresshas a few clarification functions on metal elements.

4) At Kiryu and Jakujo watershed, metal elements are being cumulated currently.

5) Concentration of K, Na, and Si in stream is larger than that of rainfall. It is because the parent substance is granite.

[REFERENCES]

[1] HUANG G H, XIA J. Barriers to sustainable water-quality management [J]. Journal of Environmental Management, 2001, 61: 1−23.

[2] LaGrega M D, Buchingham P L, Evans J C. Hazardous Waste Management [M]. McGraw-Hill Company, 2001. 372−418.

[3] Suter G W Ⅱ, Barnthouse L W, Bartell S M, et al. Ecological Risk Assessment [M]. Lewis Publishers, 1993. 3−19.

[4] Cairns J Jr, Niederlehner B R, Orvos D R. Predicting Ecosystem Risk [M]. Princeton Scientific Publishing Co., Inc., 1992. 1−8.

[5] Katayama Y. On the clarification functions of forest to environmental pollution substance [D]. Kyoto University, Japan, 1990. 1−67.

[6] Iwazubo G. On the Influence of Forest Type and Forest Age to the Quality and Quantity of Stream in Forest Hydrology, Study on Ecology [M]. Japan Education Department, 1993. 1−90.

[7] Soomiya I. Purifying Constitution of Nature [R]. Japan Technique Report Hall Press, 1990. 39−59.

[8] Chigayano Z, et al. Heavy Metal and Living Things, Share Association [M]. Philanthropy Fellowship, 1998. 81−142.

[9] Tsutsumi T. Material Recycling of Forest [M]. Tokyo University Press, 1987. 1−99.

[10] Hicks W K, Leith I D, Woodin S J, et al. Can the foliar nitrogen concentration of upland vegetation be used for predicting atmospheric nitrogen deposition? Evidence from field surveys [J]. Environmental Pollution, 2000, 107: 367−376.

[11] Kozlov M V, Haukioja E, Barkhtiarov A V, et al. Heavy metals in birch leaves around a nickel-copper smelter at Monchegorsk, northwestern Russia [J]. Environmental Pollution, 1995, 90: 291−299.

(Edited by YUAN Sai-qian)