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Element cycling in the dominant plant community in the Alpine tundra zone of Changbai Mountains, China

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Abstract: Element cycling in the dominant plant communities including *Rh. aureum*, *Rh. redowskianum* and *Vaccinium uliginosum* in the Alpine tundra zone of Changbai Mountains in northeast China was studied. The results indicate that the amount of elements from litter decomposition was less than that of the plant uptake from soil, but that from plant uptake was higher than that in soil with mineralization process released. On the other hand, in the open system including precipitation input and soil leaching output, because of great number of elements from precipitation into the open system, the element cycling(except N, P) in the Alpine tundra ecosystem was in a dynamic balance. In this study, it was also found that different organ of plants had significant difference in accumulating elements. Ca, Mg, P and N were accumulated more obviously in leaves, while Fe was in roots. The degree of concentration of elements in different tissues of the same organ of the plants also was different, a higher concentration of Ca, Mg, P and N in mesophyll than in nerve but Fe was in a reversed order. The phenomenon indicates (1) a variety of biochemical functions of different elements, (2) the elements in mesophyll were with a shorter turnover period than those in nerve or fibre, but higher utilization rate for plant. Therefore, this study implies the significance of keeping element dynamic balance in the alpine tundra ecosystem of Changbai Mountains.

Keywords: element cycling; ecosystem; dominant plant community; alpine tundra zone; Changbai Mountains

Introduction

In the recent literature, element cycling and variation have been studied in various locations in many different types of mountain ecosystem (Conlin, 2001; Stottlemyer, 2000; Groffman, 2001; West, 1999; Binkley, 1991). Nagaraju and Karimulla (Nagaraju, 2001; 2002) examined the accumulation process of elements(B, Mn, Sr, Zn, Fe, Be) in plants and soils, and identified the biogeochemical behavior of these elements. Rueth *et al*. (Rueth, 2002) compared biogeochemical processes of C, N, Ca, Mg, P of spruce in forest stands in the Colorado, USA. Rutigliano, Hrdlicka and Kula (Rutigliano, 1998) studied the dynamics of nutrient elements(N, P, K, Ca, Mg) in decaying leaves and element contents of S, N, P, Ca, Mg, K, Mn, Zn, Cu in leaves of birch in many air polluted areas. In addition, many researchers reported plant patterns, plant ecology and climate of the Alpine tundra zone in different regions (Bliss, 1994; Myenia, 1997; Henry, 1997; Fagre, 2000). However, little research attention has been given to element cycling in Alpine tundra zone. This paper concentrates on element cycling in plant community in Alpine tundra zone of Changbai Mountains in the northeast of China. It attempts to examine the element dynamics in the ecosystem of Alpine tundra zone in the mountain.

The Changbai Mountains is the highest peak in Northeast China with elevation of 2691 metres above the seas level. Located along the eastern Asia monsoon region of the Pacific Ocean, it lies in 41°58′—42°6′N and 127°54′—128°8′ E. According to Huang(Huang, 1959; 1984), Changbai Mountain's vegetation pattern is very complex and four vegetation zones can be identified from the peak to the foot of the mountain, i.e. Alpine tundra zone, elfin birch forest, taiga forest, and coniferous-broad-leaved mixed forest. Alpine tundra zone lies above approximately 2000 m asl (Huang, 1959; 1984). According to the last 30 years' weather record by a Climate Station(2670 m asl; adjacent to the crater lake of the Changbai Mountains), the mean annual temperature is −7.3℃, mean temperature in January is −21.4 to −22.7℃ and 10.2 to 12.4℃ in July, the mean annual precipitation is 1075—1238 mm, and the relative annual humidity reaches 74% in average. The climate condition in this alpine tundra is harsh: cold, windy, snowy, and low growing season temperature and a short frost-free period. In the zone the plants are typically small, close to the ground. The vegetation consists of low growing shrub, cushion plant, small forbs exploding with colorful flower. The plant species in the zone are dominated by dwarf shrubs and herbs, such as *Rh. aureum*, *Rh. redowskianum*, *Vaccinium uliginosum*, *Rh. confertissimum*, *Dryas octopetala var. asiatica* (Liu, 1993). Under such an extreme condition, the soil in the zone has been identified as a kind of tundra soil with peat, indicating highly influenced by soil formation factors, such as matrix, climate, topography, and microbial activity(Meng, 1982).

1 Materials and methods

1.1 Sample site describing and amounts of different carrying substances

To understand the element cycling pattern in plant community in Alpine tundra zone of Changbai Mountains, we carefully selected sample location and analysis method. The coverage(%) plant community was estimated in 220 plots that were randomly selected using a loop in diameter 30 cm in the Alpine tundra zone from 2000 m to 2600 m asl. Above-ground biomass and below-ground biomass of three kind of species were determined from 40 sample sites (25 cm × 25 cm) in the zone. Twigs and leaves of the plants were

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weighted *in situ*, and biomass was calculated respectively. Below-ground biomass was determined by weight of all roots from the sample sites. Fifteen shrub twigs with leaves were randomly sampled from all shrubs of each sample site; the age of every shrub twig slice was read below anatomical lens. To study element cycling in the zone, the concentration and amount of elements following different substances were measured: precipitation, soil leaching water, throughfall and stemflow(Ivens, 1990), plant roots, twigs and leaves, total litterfall on ground, litterfall, and decomposed litter. According to the amount of elements in the different substances, element cycling characteristic was calculated. In this study, 10 undisturbed spots with different plants communities in elevations were selected for installing the tensionless tray. Each tensionless tray collectors with 25 cm in length ×25 cm in width ×3 cm in height that is made of PVC board was installed in between soil A horizon and C horizon. The water volumes from soil leaching to collectors for two summers in the tundra zone were 1.47×10^8 ml/(hm^2·a). Litter decomposition rates were determined by the litter bag technique(Bocock, 1964), modified by Rustad and Cronan(Rustad, 1988). The mesh size of bag with 1 mm acrylic-coated mesh allows for the movement of most soil fauna into the litter bag (Edwards, 1963) facilitating decomposition and preventing loss of debris. The bags were placed in subplots within each plot. After 100 d and 450 d, litter bags were collected to determine the average decomposition rate, respectively.

The following equations were used to calculate the biomass and production:

Each shrub average growing rate(gi) was calculated by the following equaion:

$$gi = \frac{Wyi}{Yi}, \quad i = 1,2,3,\cdots, n. \tag{1}$$

Where Wyi is the each shrub twig weight; Yi is each twig age; gi is the each shrub twig average growth rate. The all shrubs average growth rate(R) in each sample site was calculated by coefficient of the age ratio of each twig:

$$R = \sum_{i=1}^{n}(gi + Li)/n, \quad i = 1,2,3, \cdots, n. \tag{2}$$

Where Li is the age ratio of each twig; let $Li \geqslant 0$, $\sum_{i=1}^{n} Li = 1$, then above-ground production was calculated by the following formula:

$$Gi = \frac{Ti}{ti} Ri \times Pi. \tag{3}$$

Where Gi is the production; Ti is the all shrub weight in each sample site; ti is the total weight of 15 shrubs by sampling randomly in each sample site; Pi is the shrub numbers by sampling randomly in each sample site; Ri is the all shrubs average growth rate in each sample site. Below-ground production was determined with the same method. The biomass of above-ground and below-ground were obtained after weighting *in situ* and air-dried.

1.2 Analysis methods

The concentrations of elements in precipitation and soil leachage were determined by GBC-906, AAS, the concentrations of element in plant and litter were determined by ICPS-7500, mean value of each sample from 3 replicates was carried out. The concentration of N in the all samples was analyzed with the routine chemical method.

2 Results and discussion

2.1 Biomass, production, amounts of litterfall and litter decomposition rate

The results are summarized in Table 1 and Table 2. Table 1 shows that above-ground biomass is less than that of below-ground biomass. On the average, total biomass of the above-ground is about half of that in the below-ground. But above-ground production is much higher than that of below-ground production(Table 1). This indicates that root has a lower fade rate than that of twigs and leaf. Above-ground biomass and below-ground biomass of three types of communities in the Alpine tundra zone accounted for 86%, 62% of total Alpine tundra zone, respectively. These three shrub species are dominant community in the zone. The litter decomposition rate, litterfall, decomposition amount, and residual amount are shown in Table 2. It is clear that the decomposition rates among the three litter types in this study were not significantly different. Our interpretation is that the factors affecting decomposition rate, such as litter quality, soil properties, microbial communities, and climate, were of minor different among the three communities. Mass loss rate of three litter types for 2 growth seasons *in situ* incubation period was approximately 13%, and the remained mass was about 87%.

Table 1 Biomass and production of Alpine tundra zone

Plants	Biomass, t/hm^2				Production, t/(hm^2·a)				Cover, %
	Above-ground			Below-ground	Above-ground			Below-ground	
	Twig	Leaf	Total		Twig	Leaf	Total		
Vaccinium uliginosum	1.06	0.57	1.64	3.24	0.39	0.20	0.59	0.115	24
Rh. Aureum	0.68	0.62	1.30	1.67	0.17	0.16	0.33	0.048	10
Rh. redowskianum	0.44	0.28	0.72	1.45	0.17	0.12	0.29	0.048	10
Three communities	2.18	1.47	3.65	6.36	0.73	0.48	1.21	0.211	44
Total Alpine tundra zone	2.53	1.69	4.22	10.3	1.16	0.67	1.83	0.480	94

Table 2 Litterfall and litter decomposition rate

Plants	Decomposition rate, % ($n = 3 \times 30$)	Total litterfall, t/hm^2	Litterfall, $t/(hm^2 \cdot a)$ ($n = 3 \times 15$)	Decomposition amount, $t/(hm^2 \cdot a)$	Residual amount, $t/(hm^2 \cdot a)$
Vaccinium uliginosum	13.48	2.20	0.44	0.06	0.38
Rh. Aureum	11.43	1.35	0.20	0.02	0.18
Rh. Redowskianum	14.40	0.48	0.19	0.03	0.16
Three communities	13.10	4.03	0.83	0.11	0.72
Tundra zone		7.13			

2.2 Concentration and amount of elements in precipitation, leachates and organs of the plant

The precipitation stands out as a major source of nutrient substances in the ecosystems of the Alpine tundra zone of Changbai Mountains. As Table 3 shows, the precipitation contained quite large amount of nutrient substances. It is also to soil leaching which is a main reason for elements loss from the zone. For example, Ca, Mg, N and P leached out from soil profile in the Alpine tundra zone are 6.04 kg/($hm^2 \cdot a$), 0.15 kg/($hm^2 \cdot a$), 0.27 kg/($hm^2 \cdot a$), 0.052 kg/($hm^2 \cdot a$), and account for 52%, 7%, 3% and 11% in precipitation, respectively (Table 4). Amount of element concentration in each organ of plants are shown in Table 5. The results show that amount of concentration of Ca, Mg, N and P in leaf is higher than that of other parts, and concentration of Fe in root is higher than that of other organs. Comparing the concentration of elements in litter with that in root, leaf and twig, it is found that the concentration of elements in mesophyll is higher than that in nerve or fibre. This indicates that different tissues (mesophyll and fibre) in the same organ have various capacities to accumulate different elements. The difference fully reveals the biochemical function of elements.

Table 3 Concentration and amount of elements from precipitation

Elements	Fe	Ca	Mg	Mn	P	Sr	Zn	N
Concentration, mg/L	2.8×10^{-2}	2.1	0.43	3.3×10^{-2}	7.9×10^{-2}	3.1×10^{-3}	1.1×10^{-2}	1.48
Content, g/($hm^2 \cdot a$)	159.2	11705.5	2130.7	184.6	438.6	19.2	52.4	8089.0

Table 4 Concentration and content of the elements from soil profile leaching output (mg/L)

Items	Fe	Ca	Mg	Mn	P	Sr	Zn	N
Vaccinium uliginosum	0.172	5.76	0.715	2.20×10^{-2}	5.10×10^{-1}	1.20×10^{-2}	6.90×10^{-2}	1.85
Rh. aureum	0.161	5.178	1.512	2.59×10^{-2}	9.80×10^{-3}	2.03×10^{-2}	3.00×10^{-2}	0.65
Rh. redowskianum	0.263	4.357	0.292	1.83×10^{-2}	1.58×10^{-2}	6.70×10^{-3}	3.50×10^{-2}	1.48
Alpine tundra zone, g/($hm^2 \cdot a$)	34.6	6044.8	145.3	4.0	50.18	2.3	11.5	267.1

Table 5 Concentration of elements in each organ (mg/kg)

Items	Plant organs	Fe	Ca	Mg	Mn	P	Sr	Zn	N*
V. uliginosum	Root	17039	102674	18177	36778	20111	502	1576	0.81
	Twigs	8411	136618	24812	56212	42674	474	3302	0.95
	Leaf	1578	170749	36086	34090	31282	232	435	1.66
	Litter	21118	67538	7710	13598	7287	258	524	1.44
Rh. aureum	Root	2461	141852	17206	35554	17649	728	1403	0.89
	Twigs	7816	153551	20073	53694	25663	722	1428	0.55
	Leaf	886	99334	15694	25438	17613	259	353	1.23
	Litter	12855	115566	11577	21102	6163	435	484	0.86
Rh. redowskianum	Root	20413	108961	16208	27559	15372	614	1334	0.83
	Twigs	12056	130160	20440	24979	27836	669	2134	0.62
	Leaf	3248	191034	37899	10902	51025	434	791	1.98
	Litter	19553	60931	6917	6262	5178	253	380	1.23

Notes: * it is in percentage.

2.3 Element contents in the different substances and the amounts of input and output of elements in Alpine tundra zone

The element amounts from litter decomposition and precipitation, as well as that of shrub uptake and of leaching output from soil profile are shown in Table 6. It is found that amounts of N and P uptaken by plants and leached from soil were higher than that of litter decomposition and precipitation. So we can conclude that N and P are lacking in plant-soil system. N and P amounts from litter decomposition are not far enough for plants uptake, but those from precipitation input are 5—10 times higher than that of litter decomposition. Precipitation becomes a major reason for increasing chemical substances into the ecosystem. This can be further confirmed by the fact that the amounts of Ca and Mg input by precipitation to soil are 10 times higher than that of litter decomposition, and Sr and Zn are 6 times higher. In contrast, amounts of Ca, Mg and Zn output are higher than that from litter decomposition, although element amounts output by soil leaching are far lower than that input by precipitation. Therefore, substances in precipitation and from soil leaching directly influence the nutrient balance of the

Alpine tundra ecosystem(Table 7). The amount of input and output of elements in the Alpine tundra zone is listed in Table 8. From Table 8, we conclude that the input amount of element from precipitation, decomposition, throughfall and stemflow is 15.72 kg/($hm^2 \cdot a$) more than that of soil leaching output and plants uptake.

Table 6 The element amounts of precipitation and decomposition, uptake and leaching (g/($hm^2 \cdot a$))

Plants	Items	Fe	Ca	Mg	Mn	Zn	Sr	N	P
V. uliginosu	Precipitation and decomposition	253.9	6880.7	1347.5	207.9	36.3	11.4	5317.0	294.9
	Uptake and leaching	134.2	7999.2	524.9	488.9	36.9	7.4	8120.4	605.2
Rh. aureum	Precipitation and decomposition	56.3	2868.7	363.2	296.2	20.2	4.6	2091.5	110.3
	Uptake and leaching	59.3	1565.3	259.4	38.7	11.5	5.6	3357.7	227.2
Rh. redowskianum	Precipitation and decomposition	114.5	2930.9	574.5	67.3	15.2	4.9	2215.5	121.3
	Uptake and leaching	99.3	1589.4	262.9	179.3	14.7	5.4	3903.9	330.4

Table 7 Element contents in the different substances of the Alpine tundra zone (g/($hm^2 \cdot a$))

Items	Ca	Mg	N	P	Fe	Mn	Zn	Sr
Precipitation	11705.54	2130.74	8089.00	438.63	159.15	184.64	52.36	19.16
Root uptake	587.71	91.96	1751.26	96.76	101.94	179.35	7.79	3.02
Twig uptake	1878.62	303.48	56.91	474.29	126.70	635.91	35.16	7.89
Leaf uptake	2638.80	506.31	7672.60	540.94	29.98	245.00	8.69	5.25
Litterfall	7182.75	797.07	1042.25	651.80	1944.85	1253.84	47.64	27.92
Decomposition	955.42	106.44	1385.90	487.91	265.16	165.20	6.42	3.12
Residual	6231.54	691.06	9026.30	564.14	1680.30	1089.21	41.24	24.20
Total litterfall, g/hm^2	7542.42	4136.99	53679.00	3315.61	9726.36	6621.18	243.03	145.42
Throughfall and stemflow	6209.81	1213.11	951.50	4525.56	151.54	981.29	78.06	7.58
Soil leaching output	6044.83	145.33	267.10	50.18	34.57	3.99	11.52	2.31

Table 8 The amounts of input and output of elements in Alpine tundra zone (kg/($hm^2 \cdot a$))

Input				Output		
Precipitation	Decomposition	Throughfall and stemflow	Total input	Uptake	Leaching output	Total output
22.81	3.38	14.12	40.31	17.99	6.60	24.59

3 Conclusions

From the above analysis, owing to low growing season temperature and a short frost-free period, the production of the plants is lower; mean annual productions of above-ground and below-ground are 1.83 t/($hm^2 \cdot a$) and 0.48 t/($hm^2 \cdot a$). Limited by the air temperature in the zone, mean annual litter decomposition rate is only 13%, residual amounts on the ground about 1.44 t/($hm^2 \cdot a$), total litterfall amount in the alpine tundra zone for 7.13 t/hm^2. Total amount of eight chemical elements from precipitation is 22.8 kg/($hm^2 \cdot a$), and total amount of soil leaching output is 6.6 kg/($hm^2 \cdot a$). Input amount from precipitation is 16.2 kg/($hm^2 \cdot a$) more than that of soil leaching output. Nutrient elements amount uptaken by plants from soil is 14.6 kg/($hm^2 \cdot a$) more than that of litter decomposition releasing. Compared with nutrient elements net amounts, which are 16.2 kg/($hm^2 \cdot a$) from precipitation and soil leaching output and 14.6 kg/($hm^2 \cdot a$) from plants uptake and litter decomposition releasing, we conclude that the element cycling (except N, P) in the dominant plant community in the Alpine tundra zone reaches a dynamic balance. In addition, different plant organs have various capacities to accumulate different elements. Element concentration in different tissues of the same organ (mesophyll, nerve) is diverse. Both macro and trace nutrient elements are released fast from litters and have shorter turnover period as well as higher utility rate by plants. Based on the relationship of quantitative transfer, we can artificially control some a pathway of the elements cycling for different objectives. The precipitation and soil leaching are important factor in the study of elemental cycling in the natural ecosystem. The nutrient elements input by precipitation are important sources to keep the elements balance in the ecosystem.

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