Journal of Environmental Sciences Vol. 10, No. 3, pp. 378—384, 1998 ISSN 1001—0742

Nutrient cycling characteristics of *Quercus acutissima* and *Pinus massoniana* mixed forest in the Three Gorge Reservoir area, China *

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Abstract—The cycling characteristics of nitrogen(N), phosphorus(P) and potassium(K) of the *Quercus acutissima* and *Pinus massoniana* mixed forest which is the most common forest type in the Three Gorge Reservoir areas in China, were systematically analyzed. The results showed that N, P and K accumulated in the plant pool and in the litter pool, while total N, P, and K were deficient in the soil pool and in the forest systems. Contents of N in the soil of depth 20—40 cm were the key factor limiting growth of trees. The biological outside cycling coefficients were 8.78, 72.5 and 11.7 times of inside cycling coefficients of N, P and K, respectively. 33.92, 10.26 and 15.88 kg of N, P and K return to the litter pool from branches, leaves and throughfall per year, but, 14.31, 1.32 and 10.48 kg of N, P and K return to the soil from litter pool per year respectively. It is clear that 58% of N, 87% of P, and 34% of K are lost by surface runoff per year. 5.49%, 1.30%, and 8.34% of N, P and K withdraw from leaves to branches, 4.99%, 1.99% and 7.30% of N, P and K withdraw from branches to trunks per year, respectively.

Keywords: nutrient cycling; *Q. acutissima* and *P. massoniana* mixed forest; Three Gorge Reservoir.

1 Introduction

The movement and cycling of materials is one of the most important functions of the forest ecosystems. In most of the researches, the main aspects studied are the distribution, accumulation, transportation, return, input and output of nutrient elements (Wu, 1995). However, these processes in the forest ecosystem are not mutually independent. In a forest ecosystem, different components interact and interrelate by which an econetwork structure is formed. The cycling index is a key indicator reflecting the properties integrity for nutrients cycling in a system. It depends on the structure and behavior of the system, and is not equal to the cycling components of a community(Howord, 1987). Finn(Finn, 1976) put forward a method to calculate cycling index in networks. In this paper, we selected a forest ecosystem of the *Quercus acutissima* and *Pinus massoniana* mixed forest which is the most extensive forest type in the Three Gorge Reservoir areas in China. The distribution, accumulation, transportation, return, input and output characteristics of three nutrient(N, P and K) in the forest ecosystem were systematically analyzed on this basis, and the cycling indices of the three nutrients were calculated. This might provide some scientific bases for making rational forests development measures so that we can sustainable enhance land productivity.

2 Study sites

The study sites are established at the Beijing Forestry University Experimental Station in the

* The study is one of the 9th 5-Year Key Sciences Program of China and Supported by the National Natural Science Foundation of China(Nos. 39500116 and 39670145)

Three Gorge Reservoir areas watershed, which is located in the Zigui County, Hubei Province. It has the subtropical climate. The annual mean air temperature is 18℃. The annual mean precipitation is 1015 mm, and annual evaportranspiration is 1421.5 mm. The >12℃ annual accumulative temperature is 1700, and the >10℃ annual accumulative temperature is 5700℃. The soils are yellow earth(Cai, 1997). The main plant species are *Pinus massoniana*, *Quercus acutissima*, *Cunninghamia lanceolata*, *Cupressus funebris*, *Carpinus turczanizowii*, *Rhododendron simsii*. The stand density is 4500 stock per hm^2, the ages of trees range from 6 years to 50 years, average stand height is 6.75 m, and the diameter at breast height (D.B.H.) of trees is 6.70 cm.

3 Methods

The methods of measurement for biomass of broad-leaves, coniferous-leaves, amount of litter fall and amount of decompose of litter see reference(Wu, 1994).

3.1 Measurement of the standing biomass

All trees were divided into 10 diameter(D. B. H) classes. In the same site sample, two standard sample trees in each D. B. H. class were selected, and cut down to measure the aboveground biomass of different organs. The underground parts were totally excavated, the roots were taken out and the soils were cleaned, then they were weighted in situ. One kg of sample for each organ was taken to laboratory after oven dried at 80℃ to constant weights and the dry weight was determined.

The biomass of stems, branches, leaves and roots of the trees in different D. B. H. classes were calculated according to allometric methods. The regression relationships between the biomass of different organs and D.B.H.(Wu, 1995) are shown in Table 1.

Table 1 Regression relationship between the biomass of different parts and D^2H

Parts	Regression equation *Pinus massoniana*	*r*	Regression equation *Quercus acutissima*	*r*
Trunk	$W_t = 0.07241(D^2H)^{0.9522}$	0.9765	$W_t = 0.03986(D^2H)^{1.3200}$	0.9900
Branches	$W_b = 0.05311(D^2H)^{0.6588}$	0.8600	$W_b = 0.004185(D^2H)^{1.6500}$	0.9300
Leaves	$W_1 = 0.008112(D^2H)^{0.9051}$	0.9200	$W_1 = 0.1038(D^2H)^{1.6855}$	0.9300
Roots	$W_r = 0.06278(D^2H)^{0.6070}$	0.9105	$W_r = 0.005474(D^2H)^{1.2800}$	0.9500

Notes: *W* is the biomass in dry weight(kg); *D* is D.B.H. (cm); *H* is the height(m); *r* is the correlation coefficient

1m × 1m samples quadrates were selected with a distance of 2m, 5m, 8m, 11m and 14m away from corner of the north to measure the biomass of shrubs and herb. Biomass was determined with the harvest methods.

3.2 Measurement of annual net biomass increment

Two standard sample trees in each D.B.H. class were selected. The D.B.H. of the standard trees were measured. Based on the relationships between biomass and D. B. H. of *Quercus acutissima* and *Pinus massoniana*, the biomass of different organs in the beginning and end of growth were calculated. The interval differences were the annual net biomass increments of stems, branches, and roots. The annual net increment of leaf biomass was the current-year biomass of leaves in that year.

3.3 Measurement of the litter

1m × 1m quadrate litter fall were randomly laid out in the forest. The aboveground litters were collected monthly. The dry weight of the litters was measured and calculated, on a hectare basis.

According to the measures of the litter, another ten 0.5m × 0.2m quadrates were selected for measuring underground litter. The soils in the quadrates (0—60 cm depth) were totally excavated. The dead roots in the soils were taken out. Their dry weight was measured and calculated on a hectare basis.

3.4 Measurement of rainfall, throughfall and stemflow

In gaps of forest ecosystems, 2 rain gauges, the MS-1 type, were randomly laid out (the height of the gauges was higher than that of the shrub and herb) to measure rainfalls. Under the closed crowns and under the overlaps of two crowns, two MS-1 rain gauges were laid out, respectively, to measure the throughfall. One tree in each D. B. H. class was selected to measure stemflow. The stemflow collectors made of rubber pipes were spiral out on trunks. The upper end of the pipes was fixed on the trunks, and the lower end of them was put into receiving pots at the base of the trunks.

3.5 Measurement of runoff water and the collection of soil samples

Soil samples were collected at the depth for 0—20 cm, 20—40cm, 40—60 cm, 60—80 cm for each pit. Soil bulk density was calculated. The contents of N, P and K in different horizons were calculated according to the following formula (Deangelis, 1980; Wu, 1993):

(nutrient storage) = (soil bulk density) × (soil volume) × (nutrient content).

3.6 Analysis of the nutrients

Semimicro Kjeldahl method was adopted to determine N concentration, ultraviolet spectrophotometer to determine P, and atomic absorption spectrophotometer to determine K(Wu, 1993).

4 Results

4.1 N, P and K concentrations in the plant

The biomass of plants is the major pool of nutrients in the system. It is important for us to understand the storage of nutrients and their distributions among different parts of plants. The concentrations of N, P and K in different plants' s parts in the forest ecosystem are listed in Table 2.

Table 2 Concentrations of N, P and K in parts of different tree species(mg/g)

Elements	*Quercus acutissima*				*Pinus massoniana*				Branch litter	Living litter	Root litter
	Trunk	Branch	Living leaves	Root	Trunk	Branch	Living leaves	Root			
N	0.314	1.672	6.786	2.640	0.296	1.532	5.442	3.621	0.5214	5.240	1.4350
P	0.201	0.841	0.924	1.142	0.200	0.679	0.889	0.132	0.1420	0.846	0.1321
K	0.722	1.433	2.379	2.656	0.646	1.382	2.241	1.096	0.2688	2.113	1.0260

Table 2 shows that the concentrations of total N and total K in different parts are much higher than that of total P. This implies that to maintain normal growth, plants must uptake a great deal of total N and total K. Analysis for concentrations of total N, total P and total K in the soil showed that the concentrations of total K in the soil is very high(1.2%), but the concentrations of total N is much lower. Total N concentrations in the soil, especially in the surface layer, is the key factor limiting normal growth of trees. Thus, supplying total N to the soil layer is an important measure to increase the productivity of the forest ecosystem.

4.2 Analysis of nutrients in plant's pool

The concentrations for total N, P and K of trees were 210.91, 84.38 and 202.81 kg/hm^2, respectively(Table 3). This shows that the demanding of plants for total N, P and K are greater. The great demanding of plants for total N and K often result in total N deficiency in soil, which in return limits the normal growth of plants.

Table 3 Distribution and accumulation of N, P and K in parts of plants(kg/hm^2)

Elements	*Quercus acutissima*				*Pinus massoniana*				Total
	Trunk	Branch	Living leaves	Root	Trunk	Branch	Living leaves	Root	
N	19.84	58.15	46.17	18.74	18.19	10.54	27.71	11.57	210.91
P	12.70	29.25	6.29	8.11	12.29	4.67	4.58	6.49	84.38
K	45.62	49.83	16.19	18.85	39.71	9.51	11.41	11.69	202.81

4.3 Nutrient accumulation, nutrients in litters, and nutrients in plant parts

The annual nutrient uptakes, nutrients in annual litter and nutrients accumulation can be calculated (Table 4).

Table 4 Nutrient accumulation, nutrients in litters, and nutrients in plant parts(kg/hm^2)

Item		Formed trees*				Shrub & herb	Total
		Trunk	Branch	Leaf	Root		
Amount of nutrients stored in plants	N	7.61	13.74	55.41	6.06	5.32	88.17
	P	5.00	6.78	7.82	2.68	3.01	25.29
	K	17.06	11.84	19.99	7.67	8.24	64.83
Nutrients in annual litterfall	N	0.00	1.10	9.40	2.20	2.70	15.4
	P	0.00	0.60	6.80	1.20	0.1	8.70
	K	0.00	0.90	7.50	2.80	3.2	14.4
Amount of accumulation	N	7.61	13.751	55.504	6.082	5.347	88.294
	P	5.00	6.786	7.888	2.692	3.011	25.377
	K	17.06	11.879	20.065	7.698	8.272	64.947

* Blossom and fruit are not considered

It can be seen from Table 4 that the amount of N, P and K were 88.17, 25.29 and 64.83 kg/(hm^2·a), in which formed trees make up 94.4%, 88.6% and 83.9%, shrub and herb make up 5.6%, 11.4% and 16.1%; nutrients in the annual litter were 15.40, 8.70 and 14.40 kg/(hm^2·a), in which formed trees make up 82.5%, 98.9% and 77.8%, shrub and herb make up 16.5%, 1.1% and 22.2%: the net accumulation were 88.294, 25.377 and 64.947 kg/(hm^2·a), in which formed trees make up 93.9%, 88.14%, and 87.31%, shrub and herb make up 6.1%, 11.86% and 12.69%, respectively.

4.4 Analysis of nutrients in litter pool

The litter is an important part in biogeochemical cycles of nutrients. It is the major pathway by which nutrients in plants return to the soil. It plays a very important role in maintaining the stability and sustainability of the ecosystems.

Table 5 Accumulation of nutrients in the litter (kg/hm^2)

Nutrient	Dead branch	Dead leaves	Dead root	Annual litterfall	Total
N	0.15	1.31	0.18	15.40	17.04
P	0.04	0.21	0.02	8.70	8.95
K	0.08	0.53	0.16	14.40	15.17

Table 5 shows that the accumulations of total N, P and K in the litter pool are 17.04, 8.59 and 15.17 kg/hm^2. We can see from Table 4 and Table 5 that the annual litter return makes up 90.38%, 97.21% and 94.92% for total N, P and K respectively; dead branches makes up 0.88%, 0.45%, and 0.53%; dead leaves make up 7.69%, 2.35% and 3.49%; dead roots makes up 1.06%, 0.22% and 1.05%, in litter pool, respectively.

4.5 Analysis of chemical composition of rain water

Rain water is an important part in the forest ecosystems, and the major pathway in biogeochemical cycles of nutrients. The chemical composition of rain water, stemflow, and throughfall are listed in Table 6.

Table 6 Contents of nutrients in rain water(g/hm^2)

Item	*Pinus massoniana*		*Quercus acutissima*				
	NH_4^+	NO_3^-	NH_4^+	NO_3^-	N	P	K
Rain water	1.90	1.644	1.90	1.644	1.92	0.40	0.27
Stemflow	0.68	2.55	4.97	2.85	3.17	0.59	0.33
Throughfall	19.36	7.03	14.65	10.30	15.50	0.56	0.31

Table 6 shows that the contents of total N, P and K input into forest ecosystems increased by rain water. Stemflow makes up 20% of nutrients, and throughfall makes up 40% of nutrients. Concentrations of N, P and K have increased by 2.786, 0.51, 0.276 kg/hm^2, respectively, in stemflow, 14.732, 0.40, 0.202 kg/hm^2, respectively, in throughfall.

4.6 Analysis of nutrients in the soil pool

The soil is the major storage pool of nutrients, and the main source of nutrients required by plants for growth and development. N, P and K accumulations in the soil pool in the forest ecosystems are listed in Table 7.

Table 7 Concentration of available nutrients in soil(mg/g)

N		P		K	
Range	Mean	Range	Mean	Range	Mean
0.011—0.186	0.09	0.006—0.061	0.01	0.059—0.35	0.18

Table 7 shows that available N and P are largely distributed in the upper soil(0—20 cm).

Contents of available N, P and K in soils from 0 to 20 cm are 1117. 910 kg/hm^2 and 56 times of that in soils from 20 to 40 cm, respectively. The vertical distribution of available N, P and K are shown in Fig. 1.

Fig. 1 shows that the contents of N, P and K from 20 to 40 cm in soils are the key factor limiting the growth and development of trees.

4.7 Based on the analysis above, N, P and K cycling processes in the forest ecosystems are shown in Fig. 2

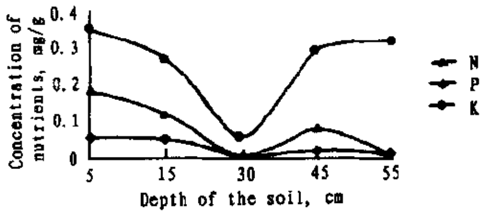

Fig. 1 The distribution of available amount of nutrients in depth of the soil

In Fig. 2, X_1 is 40.408, 12.04, 21.058; X_2 is 37.648, 10.54, 18.348; X_2' is 1.88, 0.21, 1.34; X_2'' is 1.10, 0.60, 0.90; X_3 is 31.882, 9.22, 15.832; X_3' is 1.75, 0.12, 1.23; X_4 is 15.40, 8.70, 14.40; X_5 is 14.31, 1.32, 10.48; X_6 is 41.808, 13.04, 22.658; X_6' is 0.82, 0.21, 0.74; X_7' is 1.92; 0.40, 0.27; X_7'' is 15.50, 0.56, 0.31; X_7''' is 3.17, 0.59, 0.33. X_i is annual floating amount of N, P and K, respectively, its unit is kg.

Fig. 2 shows that biological outside cycling (Wu, 1994) contents of N, P and K were 15.40, 8.70 and 14.40 kg/(hm^2·a), biological inside cycling(Wu, 1994) contents were 1.75, 0.12 and 1.23 kg/(hm^2·a), outside cycling coefficients were 0.368, 0.667 and 0.636. Inside cycling coefficient were 0.0419, 0.0092 and 0.0543, respectively.

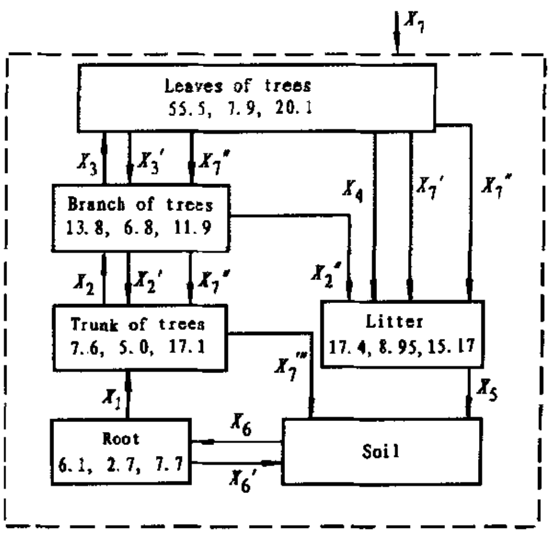

Fig. 2 The cycling of N, P and K in the forest systems, kg/(hm^2·a)

5 Conclusions and discussion

N, P and K accumulated in the plant pool and in the litter pool, while total N, total P and total K were deficient in the soil pool and in the whole ecosystem.

The N content from 20 to 40 cm in soils was the key factor limiting the normal growth and development of trees. 41.808, 13.04 and 22.658 kg of N, P and K were uptake by trees per year, 40.408, 12.04 and 21.058 kg were passed on from roots to trunks per year, 37.648, 10.54 and 18.348 kg were passed on from trunks to branches per year, and 31.882, 9.22 and 15.832 kg were passed on from branches to leaves per year, respectively. However, 14.31, 1.32 and 10.48 kg of N, P and K were returned to soils by litter from plants, respectively. The biological outside cycling coefficients were 8.78, 72.5 and 11.7 times of inside cycling coefficients for N, P and K, respectively. 33.92, 10.26 and 15.88 kg of N, P and K were returned to the litter pool by dead branches, dead leaves and throughfall rain water per year. 14.31, 1.32 and 10.48 kg of N, P and K were returned the soils from litter pool per year, respectively. It is clear hat 58% of N, 87% of P and 34% of K were lost by surface runoff per year. 5.49% of N, 1.30% of P and 8.34% of K of annual accumulation went back from leaves to branches, 4.99% of N, 1.99% of P, and 7.30% of K of annual accumulation went back from branches to trunks.

Acknowledgments——The author thanks Prof. Gao Lin of Department of Systems Ecology, Research Center for Eco-Environmental Sciences, the Chinese Academy of Sciences, and Dr. Wang Q. L. of Institute of Applied Ecology, the Chinese Academy of Sciences for their constructive suggestions.

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(Received for review February 26, 1998. Accepted March 23, 1998)