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RESEARCH ARTICLE

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Biocycle of nitrogen in a *Cyclobalanopsis glauca*-dominated evergreen broad-leaved forest in East China

Abstract The nitrogen (N) cycling was elucidated in a 40-year-old subtropical evergreen broad-leaved forest dominated by *Cyclobalanopsis glauca* growing on red soil in Zhejiang Province, East China. The concentrations of N in the representative species ranged from 0.49% to 1.64%, the order of which in various layers was liana and herb layers > understory layer > tree and subtree layers; in various organs was leaf > branch > root > trunk; and aboveground parts > underground parts. The sequence of the concentrations of N in *C. glauca* was understory > tree > subtree layer; young and high-growing > old organs; reproductive > vegetative organs. Seasonal dynamics of the concentrations of N in *C. glauca* in the tree and subtree layers was comparatively stable. It was lower in autumn (October) in root, branch, and leaf in the tree layer, and low in January in the understory. There was no evident change in regularity of the concentrations of N in varying diameter classes. The concentrations of N in the litterfall, precipitation, throughfall, litter layer, and soil were 0.74%–2.30%, 0.000,038%, 0.000,09%, 1.94%, and 0.59%, respectively. The standing crop of N in the plant community was 1,025.28 kg/hm^2, accumulation in the litter layer was 224.88 kg/hm^2, and reserve in the soil was 55,151 kg/hm^2. Annual retention of N was 119.47 kg/hm^2, return was about 84.13 kg/hm^2, among which litterfall was 78.49 kg/hm^2 and throughfall, 5.64 kg/hm^2. Annual absorption of N was 203.60 kg/hm^2. Annual input of N through incident precipitation was 4.88 kg/hm^2. Compared with other forest types, cycling rate of N in the community was lower than in deciduous broad-leaved forests, rain forests, and mangroves, and was moderate in evergreen broad-leaved forests. N use efficiency of this forest was moderate among the forest types cited. According to the characteristics of the biocycle of phosphorous, it was concluded that N availability in the soil of this forest was not lower, and phosphorous not N was the limiting factor in the growth of plants in this community.

Keywords cycling rate, *Cyclobalanopsis glauca*, evergreen broad-leaved forest, nitrogen cycling, use efficiency

1 Introduction

Nutrient cycling is a chief way of producing organic matter in the forest ecosystem (Neelu and Lodhiyal, 2003). Utilization, circulation, and fluxion of nutrients connect organic matter and soil system (Lodhiyal and Neelu, 1997). During the 1950s and 1960s, scientists had systemically researched the role and cycling process of nutrients in forest ecosystems, especially after putting IBP and MAB into practice (Jordan, 1985; Hüttl and Schaaf, 1995; Lodhiyal and Neelu, 1997; Treseder and Vitousek, 2001; Joanna et al., 2002; Neelu and Lodhiyal, 2003). Plenty of home fruits have been produced by cycling forest ecosystem nutrients in China since the 1980s (Chen et al., 1997; Xiang and Tian, 2002).

Biocycling of nitrogen (N), which is considered a life element, has an important effect on ecosystem pattern and process (Albert and Claus, 1995). In the past few decades, there have been many studies on N cycling in forest ecosystems. Some new methods, theories, and mechanisms have been brought forward, most of which are focused on temperate and tropical forests (Duvigneaud and Denaeyer-De, 1974; Feng et al., 1985; Lin and Lin, 1985; Xu, 1988; Mo et al., 1994; Li et al., 1996, 1997; Yu and Chen, 1998; Krug and Winstanley, 2002; Sha et al., 2002; Zheng et al., 2002). However, there are very few reports on subtropical evergreen broad-leaved forests, especially the typi-

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cal evergreen broad-leaved forests in eastern mid-subtropical China (Lin et al., 1997).

The evergreen broad-leaved forest dominated by *Cyclobalanopsis glauca* in Jiande forestry center in Zhejiang Province has the basic characteristics of typical evergreen broad-leaved forests and is one of the representative types of forests of this species (Chen, 1993; Chen et al., 1994). The target of this study was to understand the characteristics of N biocycling in typical evergreen broad-leaved forests, to comprehend the mechanisms of productivity that persisted in such ecosystems, and to provide the scientific base for sustainable forest management.

2 Methods

2.1 Plot locating

Sample plots were set at Longjiang Branch, Jiande Forestry Center in Zhejiang Province. Climate, geography, basic characteristics of the *C. glauca*-dominated evergreen broad-leaved forest and the method of plots setting, sample collection, and data analysis refers to former articles (Li et al., 1996; Yu and Chen, 1998).

The plot size was 0.12 hm^2 (50 m×40 m), and was divided into four symmetrical sections (I–IV). In sections I and IV, ten subplots were set for laying fine litter traps and litter bags, between which a pluviograph was placed for collecting throughfalls. In section II and III, four subplots (10 m×10 m) were set for collecting larger dead branches. A soil profile was dug up for sampling soil samples in each subplot. Dead leaves of herbs were randomly sampled in the plot. Live plants and litter layers were sampled inform the surrounding homotype communities.

2.2 Sample collection

2.2.1 Representative plant species sampling

C. glauca, the community constructor, was the main object in this study for tree, subtree, and understory layers. For sampling, *C. glauca* was divided into six classes of diameter at breast height (DBH) (≥15 cm, 13–14 cm, 11–12 cm, 9–10 cm, 7–8 cm, and 5–6 cm) in tree layer, into three classes of basal diameter (≥5 cm, 3–4 cm, and 1–2 cm) in subtree layer, and as one class of stem diameter (<1 cm) in understory. Furthermore, four species in each of the three layers, two species in herb layer and one liana were sampled as representative species, each of which was important for the corresponding layer (Table 1). Root, trunk, branch, and leaf were sampled from representative species in tree and subtree layers, while mixed aboveground and underground parts were collected from understory, herb layer, and liana (Li et al., 1996; Yu and Chen, 1998). Sampling was arranged during the four seasons of the year.

2.2.2 Litters and dead herbs sampling

Litters included larger branches and fine litters of woody plants. Larger branches (least diameter 1 cm) were collected at the end of every month. Fine litters, normally collected once a month or once a fortnight if there would be a large amount, were divided into small branches (diameter <1 cm), fruits, leaves, and miscellaneous components (flowers, shoots, shoot squamas, barks, etc.). Then the leaves were divided into five classes according to *C. glauca*, *Lithocarpus glaber*, *Quercus* spp., other evergreen species, and other deciduous species. The mixed dead leaves of *Woodwardia japonica* and *Carex* spp., the predominant species in herb layer, were sampled at the end of every month. The collecting and sampling lasted 2 years.

2.2.3 Precipitation and throughfall sampling

One pluviograph (MS-1 type) was placed on the open space outside the community, and two were placed inside. Collecting precipitations and throughfalls after every precipitation, the N concentration of every month was measured during 1 year.

2.2.4 Soil and litter layer sampling

Four soil profiles were dug up in plots for soil samples, and sampled in A_0, A, and B layers, respectively, for 2 years. Two transects were selected outside the plot on which twenty 0.5 m×0.5 m quadrants were set at every 5 m, in which litters in three sublayers, L, F, and H, were sampled in May and October.

2.3 Measurement in laboratory and data analysis

Plant samples were burned and then analyzed with 2400CHN made by Perkin-Elmer Ltd., USA, for N concentration. N in water and soil samples was measured using a half-dram procedure followed by colorimetric analysis.

Average concentration of N was calculated by biomass and N concentrations in different organs, species, and layers (Chen, 1993; Li et al., 1996; Yu and Chen, 1998).

N cycling rate in the community was calculated by plant nutrient turn rate (Yu and Chen, 1998). There were three methods: 1) the ratio of annual return and standing crop (CR1); 2) the ratio of annual absorption and standing crop (CR2); and 3) the ratio of return and absorption per year (CR3).

Nutrient efficiency of N in the community was counted by the method put forward by Vitousek (1982): 1) the ratio of NPP and absorption per year (UE1); 2) the ratio of fine litterfall and return amount of N via litter (UE2).

3 Results and analysis

3.1 Nitrogen concentrations in plant community

3.1.1 Nitrogen concentrations in representative species in various layers

N concentrations in representative species of various layers were between 0.49% and 1.64% (Table 1), but higher in *Millettia dielsiana* and *Carex* spp. and lower in *L. glaber*, *Ilex purpurea*, and *Loropetalum chinese*. N concentrations in liana were highest, followed by that in understory and in herb layer, and all of them were far higher than that in tree and subtree layers. This suggested that plants in understory and herb layer had a strong capability to accumulate N, which enabled them to adapt to the bottom status in the community, and the relatively lower light-compensating point (Loach, 1970). The order of N concentrations in *C. glauca* was understory (seeding) > tree (tree) > subtree (sapling), indicating that the concentration descended and then ascended with growth. It showed that *C. glauca* seedlings had a higher need and use of elements, and concentration of N, which is a nonstructural element, dropped due to fast upward growth. After it reached the canopy, N accumulation increased along with light intensity and photosynthesis. Thus, there was little difference in N concentration in species of tree layer and subtree layer. Compared with other plants, *C. glauca* had a slightly higher N concentration (Table 1, Fig. 1).

Table 1 Nitrogen concentration in representative species of various layers (%)

Layer	Species	Nitrogen concentration
Tree layer	*Cyclobalanopsis glauca*	0.68
	Lithocarpus glaber	0.53
	Castanopsis eyrei	0.59
	Quercus serrata var. *brevipetiolata*	0.62
	Alniphyllum fortunei	0.65
Understory	*C. glauca*	0.96
	Camellia fraternal	0.77
	Lindera aggregate	0.83
	Vaccinium carlesii	0.76
	Ardisia japonica	0.90
Subtree layer	*C. glauca*	0.62
	Ilex purpurea	0.49
	Ternstroemia gymnanthera	0.58
	Loropetalum chinese	0.53
	Rhododendron simsii	0.56
Liana and herb layer	*Millettia dielsiana*	1.64
	Woodwardia japonica	0.97
	Carex spp.	1.63

Differences existed among the N concentrations in different organs of representative species in various layers. Concentration in various organs of tree and subtree layer species ranked as leaf > branch > root > trunk, and as aboveground parts > underground parts in other layers (Fig. 1). N was mainly distributed in protoplasm, so the organs such as young parts of plants and tender leaves and branches where protoplasm was rich contained more N, while older organs like trunk and root contained less N. N concentration in the underground parts was not high because there was a large proportion of xylem in root (Chen, 1993).

3.1.2 Variation of nitrogen concentration in Cyclobalanopsis glauca among different organs, seasons, and diameter classes

The order of N concentration in various organs of *C. glauca* was: inflorescence > tender leaf > aged leaf > tender branch > aged branch > fine root > trunk and larger root. The highest concentration (inflorescence) was ten times more than the lowest one (trunk and larger root) (Fig. 2).

The change of N concentration in *C. glauca* tree and subtree layers was smooth from season to season, and the curve showed a similar pattern (Fig. 3), since trunk was the primary hoarding organ in either tree or subtree layer (Chen, 1993).

Seasonal change of N concentration in *C. glauca* trees was not significant (Fig. 3). N concentration in leaf in summer (July) was the lowest, which might be due to the short supply of N on account of intensive photosynthesis and respiration (another research about photosynthesis showed that respiration was most intensive in summer, so net photosynthetic rate was not high (Chang et al., 1999)). Concentrations in root, branch, and leaf were highest in autumn (October), which indicated that *C. glauca* grew fastest in this month. Seasonal change of N concentration in *C. glauca* subtrees was similar to that in trees. However, light in subtree layer was not as intensive as in tree layer; therefore no valley in the curve appeared. Moreover, N concentration in roots of subtrees was highest in July, which suggested that root absorbed much N during that month, and this correlated to N concentration in leaf. As for *C. glauca* seedlings, N concentration was highest in January and lowest in April, both in aboveground and underground parts, which showed that the seedlings accumulated N during winter, preparing for the next growing period.

N concentration in leaf was the lowest at DBH ≥ 15 cm, and was stable in other classes (Fig. 4). N concentration in root was highest when DBH was 11–12 cm, lowest when DBH was 13–14 cm, and was stable at other classes. Anyhow, N concentration changed little in different classes. Consequently, it was more reasonable to analyze nutrient concentration at different growth periods according to different layers in natural forest communities.

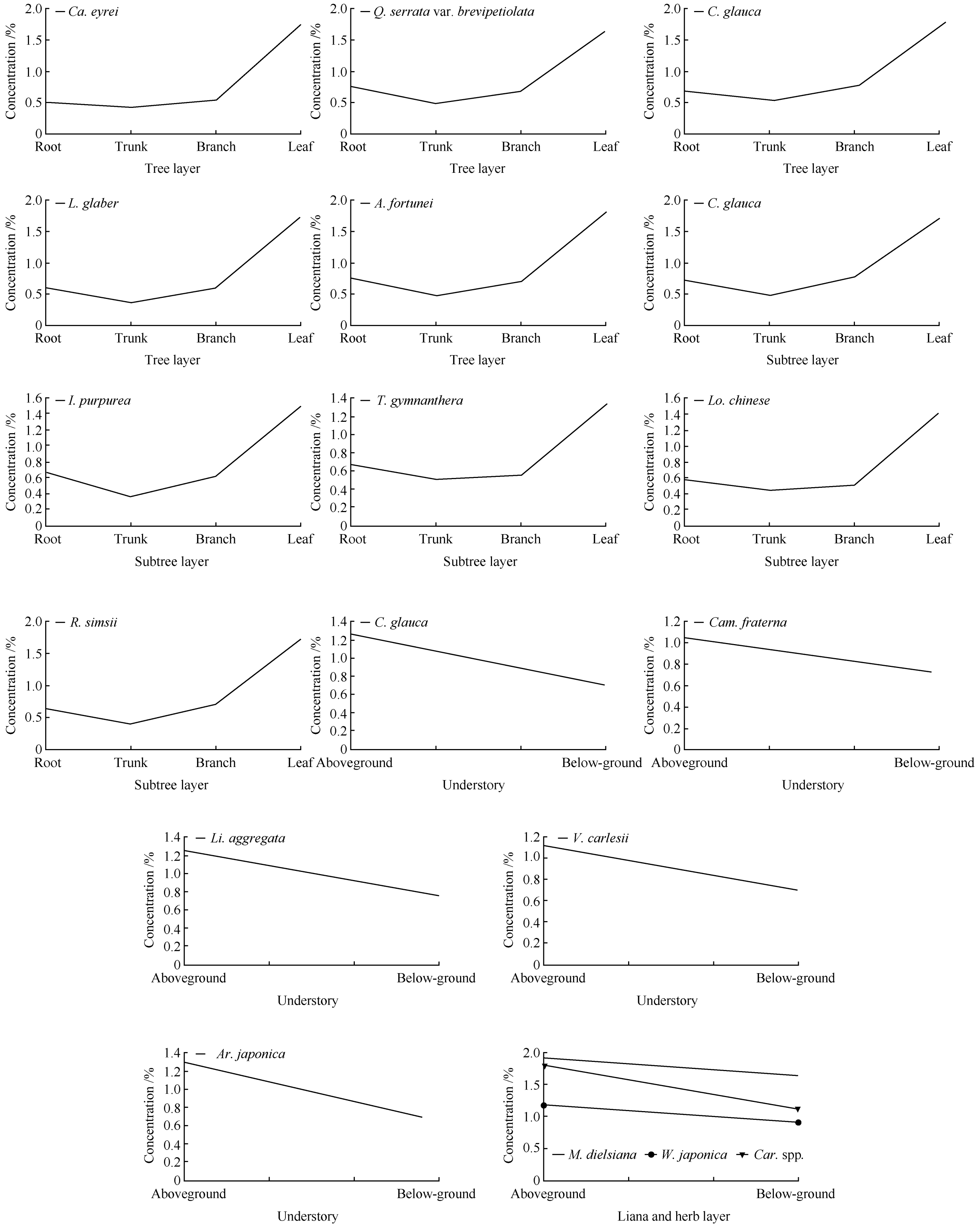


Fig. 1 Nitrogen concentration in different organs/parts of representative species in various layers

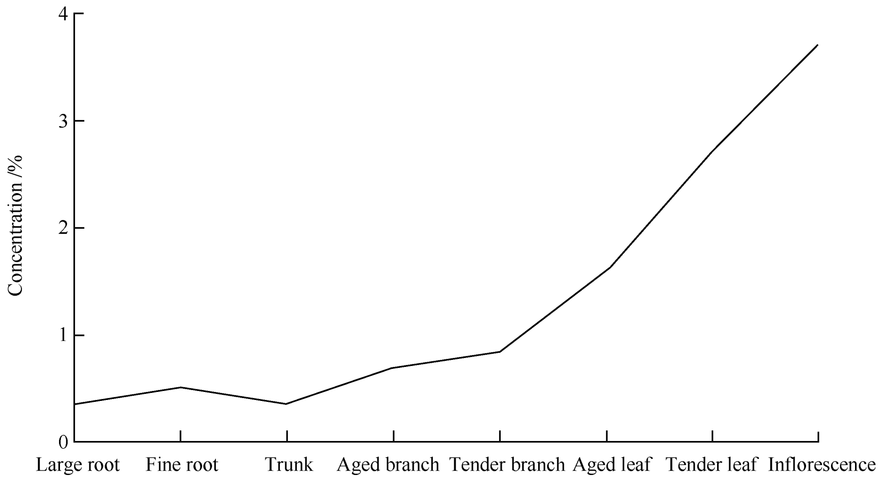


Fig. 2 Nitrogen concentration in different organs of two *Cyclobalanopsis glauca* trees

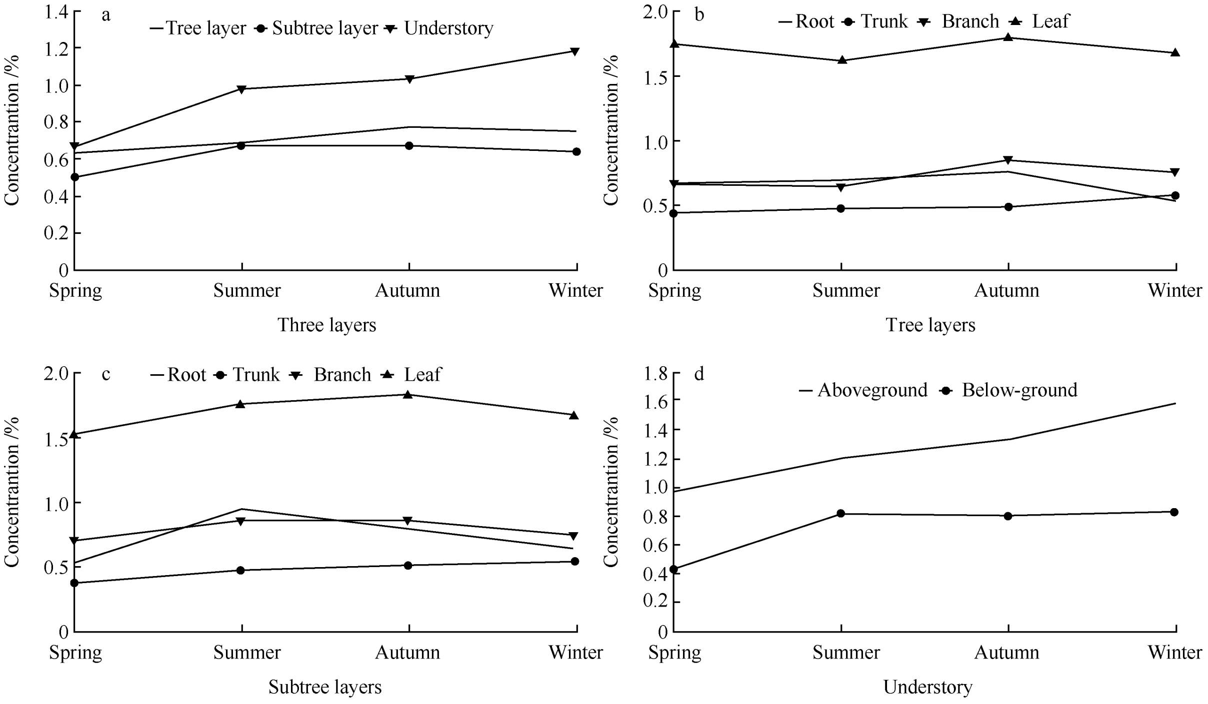
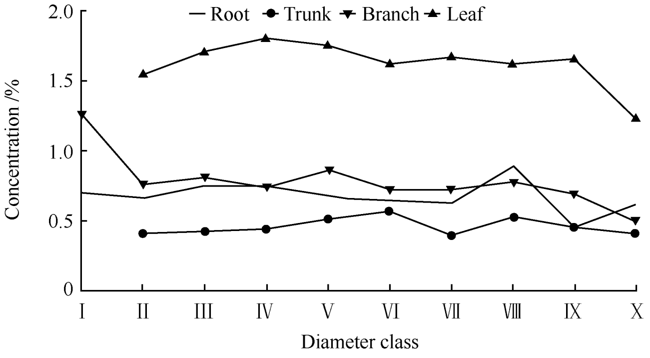


Fig. 3 Seasonal dynamics of the nitrogen concentration in different organs/parts of *Cyclobalanopsis glauca* in various layers



Class I indicates seedlings whose basal diameter < 1 cm; and classes II, III, and IV indicate saplings whose basal diameter is 1–2 cm, 3–4 cm, and ≥5 cm, respectively; V–X indicate trees whose diameter at breast height (DBH) is from 5–6 cm to ≥15 cm with an interval of 2 cm.

Fig. 4 Nitrogen concentration in various organs of *Cyclobalanopsis glauca* in different diameter classes

3.2 Nitrogen concentration in other components of the ecosystem

N concentrations of different types of litters ranged from 0.74% to 2.30% (in this study dead herbs were seen as litters and analyzed together with litters of trees). The order of N concentration in each type of litter was miscellaneous > *Quercus* spp. leaves > *L. glaber* leaves > *C. glauca* leaves > other deciduous species leaves > leaves of herbs > other evergreen species leaves > fine branches > fruit > larger branches. The order and change resembled the pattern in organs of living plants (Fig. 2, Table 2).

Table 2 Nitrogen concentration of other components in the ecosystem (%)

	Component	Nitrogen concentration
Litterfall	*Cyclobalanopsis glauca* leaf	1.81
	L. glaber leaf	1.84
	Leaf of other evergreen species	1.48
	Quercus spp. leaf	2.06
	Leaf of other summer-green species	1.73
	Fine branch	1.27
	Larger branch	0.74
	Fruit	1.07
	Miscellaneous	2.30
	Leaf of herbs	1.61
Incident precipitation	Throughfall	0.000,038
	Litter layer	0.000,090
	Litter sublayer	1.94
	Duff sublayer	2.06
	Humus sublayer	0.88
	Mean	1.59
	Soil	
	A_0 layer	0.59
	A layer	0.29
	B layer	0.22
	Mean	0.24

Seasonal dynamics of N concentration in litters are displayed in Fig. 5. N concentration in leaves and fruits of deciduous species decreased from summer to the end of December, which showed evident resorption of N before leaves and fruits fell. *C. glauca* and *L. glaber* extensively exchanged leaves, separately in April and June, while N concentration in their leaves declined a little. There was a slight change in fine and larger branches across various seasons.

N concentration in throughfall was 2.4 times that in precipitation, and was noted that some N had been eluviated when rain fell through the canopy. The ratio of N concentration in L sublayer and fresh litters was 1:2, which suggested that eluviation in L sublayer was small and that there was some enrichment in this sublayer. N concentration in H sublayer was much lower than in L and F sublayers, because microorganisms needed a mass of proteins when they decomposed litters at the beginning, and this resulted in immobilization of N in litters. Meanwhile, microorganisms fixed air N and precipitation N was input (Anderson et al., 1983). N fixation and denitrification was increasing on soil surface, so N concentration decreased from A_0 down to A and B layers in the soil (Table 2).

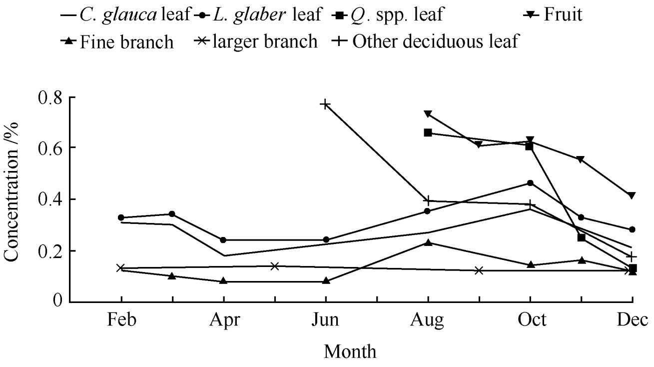


Fig. 5 Seasonal dynamics of the nitrogen concentration in several litter types

3.3 Nitrogen amount and distribution in the ecosystem

The standing crop of N was 1,025.28 kg/hm^2, and had an analogical distribution with biomass (Chen, 1993), with 89% of N allocated in tree layer. N accumulation in L and H sublayers was almost twice that in H sublayer. Although the amount of N was comparatively little in litter layer, it was a key step in the biocycle of plant-litter layer-soil-plant, because decomposition was as important as photosynthesis, which adjusted the ecosystem's progress. The soil reserved a lot of N, with 97.78% of the total in the ecosystem. The reserve in B layer was the largest and that in A_0 layer was the smallest; the allocation of N was mainly correlated to the thickness of each layer (Table 3), which showed that soil was a hinge in N cycling of the ecosystem.

3.4 Nitrogen cycling in the ecosystem

3.4.1 Components in nitrogen cycling

Like standing crop, 88.26% of nitrogen retention was accumulated by tree layer (Table 4).

Litters eaten by animals were few and therefore neglected in this study (Li et al., 1996). Throughfall and stem flow formed an important part of nutrient return (Parker, 1983). N return was measured only by litterfall and throughfall due to the exiguity of stem flow (<3% of throughfall) (Masukata et al., 1990; Ander et al., 2000). N mainly returned to soil surface via litterfall, among which the tree leaves making up 68.40%. Annual N return via throughfall was 5.64 kg/hm^2, a little more than input via precipitation every year.

Table 3 Amount and distribution of nitrogen in the ecosystem (kg/hm^2)

Components							Total
	Layer	Tree	Subtree	Understory	Herb	Liana	
Standing crop in the community		913.17	75.68	26.38	1.85	8.20	1,025.28
/%		89.07	7.38	2.57	0.18	0.80	1.82%
	Sublayer	L		F	H		
Accumulation in the litter layer		81.67		97.44	45.77		224.88
/%		36.32		43.30	20.35		0.40%
	Layer	A_0		A	B		
Reserve in the soil		1477		20609	33065		55151
/%		26.78		37.37	59.95		97.78%

Table 4 Components of annual nitrogen biocycle in the ecosystem (kg/hm^2)

Components							Total
	Layer	Tree	Subtree	Understory	Herb	Liana	
Retention /%		105.45	9.68	2.56	0.66	1.12	119.47
		88.26	8.10	2.14	0.56	0.94	
	Branch	Leaf	Other organs in woods	Herb	Via litterfall	Via throughfall	
Return /%	12.17	57.55	7.20	1.57	78.49	5.64	84.13
	14.47	68.40	8.56	1.87	93.30	6.70	
Absorption							203.60
Input of incident precipitation							4.88

Table 5 Cycling rate (CR) and use efficiency (UE) of nitrogen in some forest types

Location	Forest types	Age /year	Cycling rate			Use efficiency		Reference
			CR1	CR2	CR3	UE1	UE2	
New Guinea	Montane rain		0.18				70	Masukata et al., 1990
Gana	Lowland rain	40	0.11				53	Masukata et al., 1990
Xishuangbanna, China	Tropical seasonal rain		0.08	0.15	0.54			Xiang and Tian, 2002
Wuyishan, China	*Castanopsis eyrei* evergreen	51	0.03	0.06	0.52			Albert and claus, 1995
Fujian, China	Mangrove	20	0.14	0.23	0.61			Li et al., 1996
Australia	Eucalypt evergreen	Mature	0.20	0.20	1.00		162	Ander et al., 2000
India	Oak evergreen	Mature	0.04	0.05	0.80	81	48	Whittaker et al., 1979
Hunan, China	Chinese fir	21	0.06	0.10	0.61	180	130	Yu and Chen, 1998
Belgium	Oak deciduous	30–75	0.20	0.25	0.80	157		Lin and Lin, 1985
USA	Deciduous broad-leaved	79	0.16	0.24	0.67	128	89	Parker, 1983
Korea	*Quercus mongolica* deciduous	30–50	0.10	0.29	0.33	73	75	Edwards, 1982
Zhejiang, China	*C. glauca* evergreen	40	0.08	0.20	0.41	142	61	This paper

CR1 = return/standing cropping in community; CR2 = uptake/standing crop in community; CR3 = return/uptake; UE1 = NPP/uptake; UE2 = litterfall/return via litter fall

Absorption was the sum of retention and return (Chen et al., 1997). The *C. glauca* forest absorbed N annually 203.60 kg/hm^2 (little via aboveground organs like leaves), in which retention was about 59% and return, about 41%; the enrichment ratio (standing cropping in community/annual absorption) was 5 (Whittaker et al., 1979). So N accumulation was less than phosphorus in this 40-year-old community (Yu and Chen, 1998).

3.4.2 Nitrogen cycling rate and use efficiency

Cycling rate and use efficiency of N in some forest types are listed in Table 5. CR1 to CR3 stood for vacation, and CR3 also stood for the relation of annual uptake and turn rate. CR1 was 0.08, CR2 was 0.20, and CR3 was 0.41 in this *C. glauca* forest. UE1 was 142 and UE2 was 61.

4 Discussions

N concentrations in representative species in various layers were between 0.49% and 1.64%; the concentrations in various organs of tree and subtree layer species ranked leaf > branch > root > trunk, and aboveground parts > underground parts in other layers. N concentrations changed little among different classes. Consequently, in natural forest communities it is more reasonable to analyze nutrient concentration at different growth periods according to different layers.

There was no evident preponderance in N concentration in the communities constructor *C. glauca* compared with other representative species in the same layer. So convergence in similar habitats can be reflected. N concentrations in *C. glauca* showed understory (seeding) > tree (tree) > subtree (sapling), in which the trend showed that the concentration descended and then ascended as the tree grew up. It indicates that *C. glauca* saplings had a higher demand and use of elements, and that concentration of N, which is a nonstructural element, drops due to upward growth. When individual trees reach the canopy, accumulation of N increases along with augmentation of light intensity. Morris (1986) considered that nutrient concentration decreased due to aging of trees, and nutrients like N that could afflux in xylem had a curve relation with the tree's age, while N concentration descended at the period of early growth.

N is not a mineral element; its fixation and denitrification take place at the soil surface, so in this study N concentration in soil decreased from L to F and down to H layer with organic matter dropping off. Reserve in B layer was the largest and that in A_0 layer was the smallest, which was related to the thickness of each layer. Return via throughfall was a little more than input via precipitation per year; the latter was an important factor in N cycling (Sha et al., 2002).

N in the plant community was mainly restored in tree layers, and was about 4.6 times that in litter layer, while N reserve in the soil was 54 times that of standing crop in the plant community; thus the soil has a primary role in maintaining the ecosystem stabilization. Only 1.82% of N is restored in plant community, 0.40% returned to litter layer, and 97.78% restored to soil every year. N accumulation in litter layer was small because litters decompose fast in subtropical regions, but it was a key step in N cycling.

In this 40-year-old *C. glauca* forest community, the N CR1 was 0.08, CR2 was 0.20, and CR3 was 0.41. The rate was lower than in deciduous broad-leaved forests, tropical seasonal rain forests, and mangrove forests, and ranked middle in evergreen broad-leaved forests. The return via stem flow was scarce (<3% of throughfall) (Masukata et al., 1990; Ander et al., 2000), so throughfall could estimate the return caused by precipitation.

UE1 was 142 in the *C. glauca* forest, which was lower than in deciduous oak forest in Belgium and fir forest in Hunan, China. UE2 in this forest was 61, which was higher than in evergreen oak forest in India and tropical lowland rain forest, and was lower than in broad-leaved forest in Wisconsin, USA (UE2 = 122) (Karins and Stitht, 1999). The N use efficiency in this forest is ranked in the middle as a whole.

If soil nutrient availability were lower in the ecosystem, the nutrient use efficiency would be higher, and this would reduce the restriction of plant growth and community production (Jordan, 1985; Hüttl and Schaaf, 1995; Chen et al., 1997; Silver, 1994). Although soil pH was only 4.5–5.2 in this region, N availability was not lower compared with the soils in other tropical and temperate forests. Therefore, high use efficiency of N was not necessary for keeping community development in *C. glauca* forest, and this result was opposite to that of phosphorus (Yu and Chen, 1998). As Vitousek considered, phosphorus was the limiting factor in tropical and subtropical ecosystems, and N was the limiting factor in temperate ecosystems; our studies on phosphorus and N cycling in the *C. glauca* forest are consistent with this opinion (Rawat and Singh, 1988; Yu and Chen, 1998).

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