植物生态学报 2002, **26**(3)275～282
Acta Phytoecologica Sinica

杉木观光木混交林凋落物分解及养分释放的研究

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摘 要 通过福建省中亚热带杉木观光木混交林(*Cunninghamia lanceolata* and *Tsoongiodendron odorum* mixed forest)和杉木纯林(Pure *C. lanceolata* forest)凋落物的分解和养分释放动态试验研究表明, 凋落物各组分分解过程中干物质损失速率随时间而减小, 分解 1 年时以观光木叶的干重损失最大。各组分分解过程中 N、P 元素浓度增加而 K 和 C 元素浓度下降。混交林中各组分的养分释放速率大小为观光木叶> 混合样品(等重量的观光木叶和杉木叶混合) > 杉木叶> 杉木小枝。不同元素的释放速率与干重损失速率大小为: K> C> 干重> N ≈P。混交林凋落物的年养分释放量($kg\cdot hm^{-2}\cdot a^{-1}$)为 N 17.921, P 0.715, K 10.315, 分别是纯林的 2.03 倍、1.73 倍和 1.34 倍。与纯林相比, 混交林较高的年凋落物养分归还量和养分释放量有利于促进养分的再循环, 这对维持混交林的地力有重要作用。

关键词 杉木 观光木 混交林 凋落物 分解 养分释放

LITTER DECOMPOSITION AND NUTRIENT RELEASE IN A MIXED FOREST OF *CUNNINGHAMIA LANCEOLATA* AND *TSOONGIODENDRON ODORUM*

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Abstract Rate of litter weight loss and release of nutrient elements were investigated in a mixed forest of Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) and Tsoong' tree (*Tsoongiodendron odorum* Chun) and a pure stand of Chinese fir in Sanming, Fujian. Chinese fir needle, branch, Tsoong' tree leaf and the mixture of Chinese fir needle and Tsoong' tree leaf were involved in the 510 day period of litter bag studies. Rate of weight loss slowed with time for all litter components, with the highest percent initial weight loss of 74.54% for leaf litter of Tsoong' tree at the first year. Concentrations of N and P appeared to increase and concentrations of K and C appeared to decrease during the decomposition. The four litter components could be arranged with respect to nutrient release rate in this sequence: leaf of Tsoong' tree > the mixed leaves > needle of Chinese fir > branch of Chinese fir. Nutrient elements and weight loss followed the release pattern: K > C > dry weight > N ≈P. The total annual nutrient release of litter fall was N, 17.921 $kg\cdot hm^{-2}\cdot a^{-1}$; P, 0.715 $kg\cdot hm^{-2}\cdot a^{-1}$ and K, 10.315 $kg\cdot hm^{-2}\cdot a^{-1}$ respectively in the mixed forest, being 2.03, 1.73 and 1.34 times as much as that in the pure forest. It was concluded that the higher yield of litter production and the greater amount of nutrient release from litter in mixed forest were beneficial to nutrient cycling. Thus, a higher level of soil fertility would be expected for mixed forest than for pure forest.

Key words *Cunninghamia lanceolata*, *Tsoongiodendron odorum*, Mixed forest, Litter fall, Decomposition, Nutrient release

Chinese fir is one of the most important timber species in China, and repeating mono-culture is a common forestry practice in managing plantation of this conifer. However, soil degradation caused by continuous mono-culture with Chinese fir has received considerable attention. Some studies have found that soil deterioration mainly resulted from nutrient loss due to timber harvesting and slash burning, operational disturbance of the soil structure, and the biological feature of Chinese fir (Pan *et al.*, 1983; Zhou *et al.*, 1991; Yang *et al.*, 1998). Maintenance of soil fertility in the course of cultivating Chinese fir has aroused many concerns.

Litterfall plays a fundamental role in the forest ecosystem process; it is essential to the organic production-decomposition cycle, and it is a primary pathway of dry matter, nutrient and energy transfer from standing crop to forest soil (Melillo *et al.*, 1982; Das & Ramakrishnan, 1985; Jia *et al.*, 1998; Huang *et al.*, 1998; 2000; Zhang *et al.*, 1999; Wang *et al.*, 2001). Soil microbes and microfauna benefit from the yearly input of life substances and exert a large influence on soil fertility. Mixing Chinese fir forest with broad-leaved tree has been widely

Received: 2001-07-30 Accepted: 2001-12-03
Foundation item: The Post-doctor Research Foundation of China, the Foundation for University Key Teacher by the Ministry of Education, and the Research Project of Basic Theory of Fujian Province (2000F004)
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regarded as an effective way to maintain the long-term productivity of Chinese fir plantations (Yu, 1996; Yang, 1998; Chen *et al.*, 2001), because broad-leaved trees usually have more litter production with higher nutrient concentrations than conifers. Litterfall production, decomposition and its effect on the within-stand nutrient cycling in pure stands of Chinese fir has been widely investigated (Chen *et al.*, 1988; Tian *et al.*, 1989a; 1989b; Li, 1996; Lian & Zhang, 1998; Liao *et al.*, 1997; 2000; Chen, 1998), but there are few studies in the mixed forests of Chinese fir and broad-leaved trees. This study, therefore, was carried out to determine litter decomposition and nutrient release pattern of a mixed forest of Chinese fir and Tsoong' tree in relation to an adjacent pure Chinese fir forest.

1 Methods

1.1 Site descriptions

The study was conducted in Xiaohu work area in the Xinkou Experimental Forestry Farm of Fujian Agriculture and Forestry University, Sanming, Fujian , China (26° 11′30″ N, 117°26′00″ E). The climate is sub-tropical monsoon with mean annual temperature of 19.1 ℃ and relative humidity of 81%. Annual precipitation and evaporation are 1749 mm and 1585.0 mm, respectively. The growing season is relatively long with an annual frost-free period of around 300 days. The mixed forest and pure stand were both established in 1973, with an initial planting density of 3000 trees per hm^2. The two stands are adjacent and are closely matched in terms of slope (18°-25°), aspect (both northeast), and soil parent material (red soil derived from sandy shale). The mixed pattern is strip spacing, with three rows of Chinese fir separated by one row of Tsoong' tree. At the time of survey (at age 27), the pure stand had 1100 individuals per hm^2 with a crown density of 0.80 and a coverage of 95% for undergrowth. The mean tree height and DBH were 19.61 m and 23.6 cm respectively. The mixed stand had 907 trees per hm^2 for Chinese fir and 450 trees per hm^2 for Tsoong' tree. The mean tree height and DBH were 20.88 m and 25.1 cm for Chinese fir, and 17.81 m and 17.0 cm for Tsoong' tree respectively. The crown density was 0.95 and the undergrowth coverage was 80%.

1.2 Litter collection

Fifteen 0.5 m × 1.0 m litter traps were arranged cater-cornered in each stand, and were emptied at monthly intervals from January 1999 to January 2000. The collected litter was sorted into leaves, branches, flowers, fruits, and residues, and then oven-dried at 80 ℃ to constant weight. The litter production was estimated on the basis of dry weight per hectare.

1.3 Litter decomposition

The litter bag technique was used to study the pattern and rate of litter decomposition and nutrient release. Four litter groups were employed in the mixed forest, viz. leaves and branches of Chinese fir, leaves of Tsoong' tree, and the mixture with the equivalent mass of leaves of Chinese fir and *T. odorum*, and two in the pure forest, that is, leaves and branches of Chinese fir. The fresh litter used as the material for decomposition experiment was collected by shaking the studied trees. In May 1999, a known amount of air-dried material (50 g) of each litter group was confined in a 25 cm × 25 cm, 0.5 mm mesh size nylon bag. A total of 100 bags for each litter group was placed on the forest floor randomly within small plots in the forests from which the litters was sampled. After 30, 60, 90, 150, 210, 270, 330, 390, and 510 days of sample placement, six bags of each component were randomly reclaimed. The bags were returned to the laboratory, the adhering soil and plant detritus and the "ingrowth" roots was excluded, and the bags were then oven-dried at 80 ℃ to constant weight for the determination of remaining weight. Subsamples of each retrieving date were taken for chemical analysis.

1.4 Chemical analyses

The nutrient concentrations of the initial samples and samples of nine retrieving dates were determined. All samples were ground. For the determination of C, the plant samples were digested in $K_2Cr_2O_7$-H_2SO_4 solution by oil-bath heating and then C concentration was determined by titration. For determination of N, P, and K, the samples were digested in the solution of H_2SO_4-$HClO_4$, and then N concentration was determined on the KDN-C azotometer, P concentration was analyzed colorimetrically by the chloro molybdophosphonic blue colour method, and K concentration was determined by the atomic absorption (Science and Technology Department of the Ministry of Forestry, 1991).

1.5 Statistical analyses

The *t*-test was used to test the differences in the remaining weight of dry mass and nutrient among different components and between the predicted and observed remaining weights of mixed leaves at each sampling time. Regression analysis was done between the percent remaining weight of dry mass or nutrient amount and time using the exponential equation (Olson, 1963): $x/x_0 = \exp(-kt)$, where x is the weight remaining at time t, x_0 is the initial weight, and the constant k is the decomposing coefficient. The F-test was used to test the significance of the regression relations.

2 Results

2.1 Decomposition of dry matter

The loss of dry weight in various litter components followed the same trend: an early stage of fast decomposition followed by a subsequent slow decomposition stage (Fig.1). For instance, the needle of Chinese fir and the leaf of Tsoong' tree in the mixed forest lost 43.02% and 66.86% of their initial weight in the first 210 day period respectively, compared with 26.27% and 17.01% of those in the later 300 day period. The negative exponential equation (Olson, 1963) fitted the decomposition pattern very well ($R^2 > 0.9$, $p < 0.05$). The percentage loss of initial dry weight during the first year for various litter components were: needle of Chinese fir 56.31% and 54.71% in the mixed and pure stands respectively; branch of Chinese fir 22.28% in both stands; leaf of Tsoong' tree 74.54%; mixed leaves 69.52% (Table 1). The time required for 50% loss of dry weight for these four litter fractions in the mixed forest were 302, 991, 183 and 210 days, respectively, compared with 1303, 4280, 789 and 908 days for 95% loss. The corresponding figures for needle and branch litter of Chinese fir in the pure stand were 315 and 990 days for 50% decay; 1362 and 4280 days for 95% decay (Table 1).

2.2 Changes in nutrient concentrations

Over the 510 day period of decomposition, concentrations of N and P both increased and those of K and C decreased for each litter component (Fig. 2). In addition, the degree of variation in nutrient concentration was different among elements and litter components. After 510 days of decomposition, the degree of N increase was lower

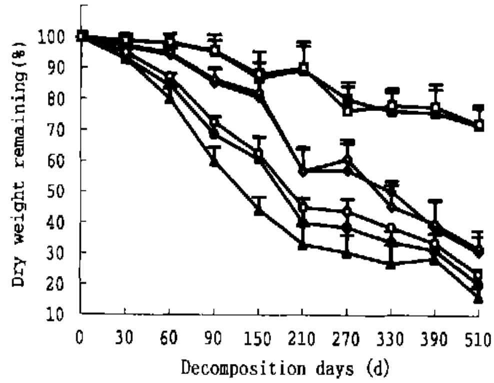

Fig. 1　Percentage of dry mass remaining in various litter groups during 510 days of decomposition

◆ Needle litter of Chinese fir in mixed forest ■ Branch litter of Chinese fir in mixed forest ▲ Leaf litter of Tsoong' s tree ● Mixed leaves ◇ Needle litter of Chinese fir in pure forest □ Branch litter of Chinese fir in pure forest ○ Predicted value for mixed leaves

The legends of the following figures are the same

Table 1　Decay rates of various litter components in the mixed and pure forests

Forest type	Litter component	Decay constant k		Correlation coefficient	Mean decay rate (per day)	Dry weight loss rate for one year (%)	50% decay time (d)	95% decay time (d)
		t (d)	t (a)					
Mixed forest	Chinese fir needle	0.0023	0.828	−0.9710	0.136	56.31	302	1303
	Chinese fir branch	0.0007	0.252	−0.9540	0.056	22.28	991	4280
	Tsoong' tree leaf	0.0038	1.368	−0.9172	0.164	74.54	183	789
	Mixed leaves	0.0033	1.188	−0.9683	0.156	69.52	210	908
Pure forest	Chinese fir needle	0.0022	0.792	−0.9675	0.134	54.71	315	1362
	Chinese fir branch	0.0007	0.252	−0.9638	0.055	22.28	990	4280

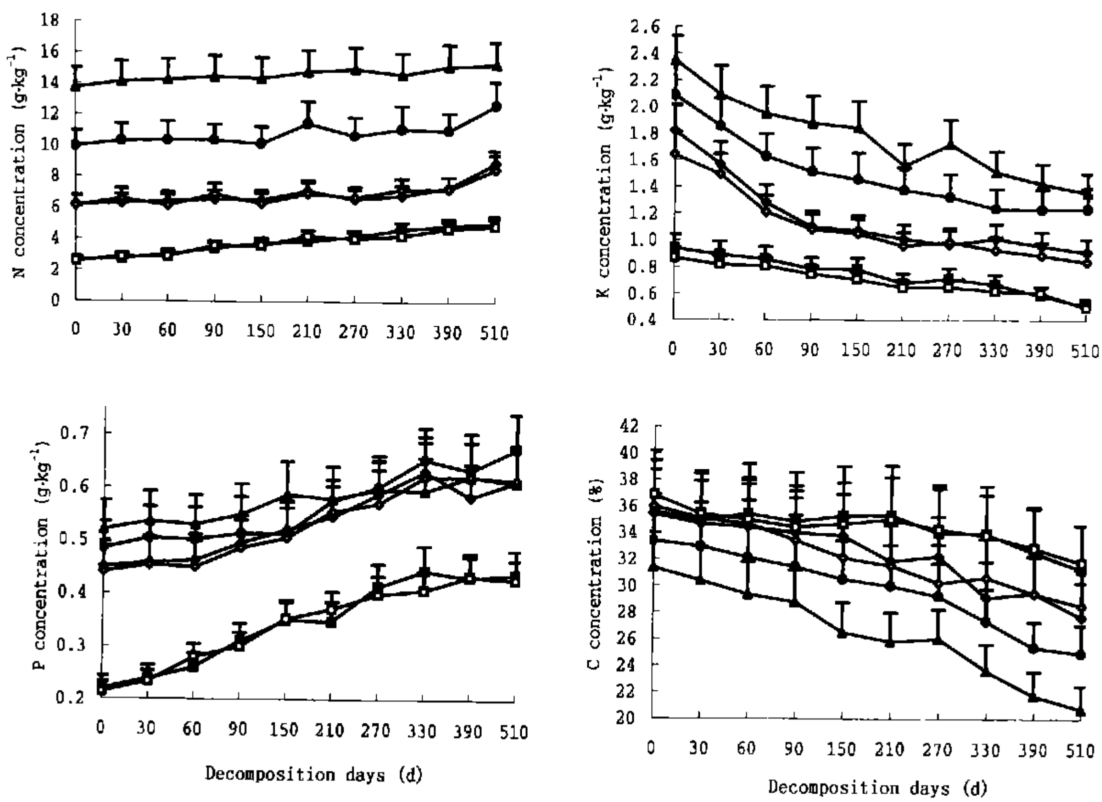

Fig. 2　Changes of concentrations of N, P, K and C in various litter groups during 510 days of decomposition

than that of P for all litter components except for Chinese fir needle, and the reduced degree of K was larger than that of C for all litter components. Furthermore, the branch litter of Chinese fir had reached the highest variation of N and P, being 94.05% and 98.18% in the mixed forest and 89.23% and 99.07% in the pure stand respectively. The needle litter of Chinese fir showed the largest decrease in K with 50.03% and 48.94% in the mixed and pure forests respectively and the largest reduction in C was found in Tsoong' tree leaf litter with 33.85%. The C:N ratios showed a decreased trend in all litter components in the course of decomposition and were in the sequence of Chinese fir branch> Chinese fir needle> mixed leaves> Tsoong' tree leaf with respect to the decreased degree after 510 days of decomposition (Fig. 3).

2.3 Changes in nutrient contents

The nutrient element contents, expressed as percentages of the initial pool size, decreased strongly in all litter components except for N and P in Chinese fir branch litter which showed large enrichment over the 510 day period (Fig. 4). The rates of nutrient element release and dry weight loss in various litter components were in the order of K> C> dry weight> N ≈P. The litter components of mixed forest could be arranged in this sequence regarding the rate of nutrient element release after 510 days: leaf litter of Tsoong' tree > mixed leaves> needle litter of Chinese fir> branch litter of Chinese fir. The percentage nutrient content remaining in different components was intimately related to the decomposing time period in a negative exponential fashion ($R^2 > 0.9$, $p < 0.05$), with the exception of N and P in Chinese fir branch litter.

In this study we compared the observed and predicted percentages of mass and element amount remaining in mixed leaf litter over the decomposition periods. The predicted values at each sampling date were estimated as the averages of percentage dry weight or nutrient amount remaining in Chinese fir needle and Tsoong' tree leaf litters. The observed values were all lower than the predictions at all dates (Fig. 4 and Table 2); furthermore, the t-test showed significant differences between the observed and predicted values for the remaining percentages of dry matter, C, N, and P ($p < 0.05$), but not of K ($p > 0.05$). Obviously, mixed leaf litters of Chinese fir and Tsoong' tree together accelerated the decomposition of dry matter and nutrients; however, this proved not true for K because it is lost mostly through leaching.

2.4 Nutrient release

Annual nutrient release from litterfall into forest soil was determined by the nutrient decay rate and annual return of nutrients in various litter components. Table 3 showed that annual nutrient release from decaying litter in the mixed forest, in $kg \cdot hm^{-2} \cdot a^{-1}$, was N: 17.921, P: 0.715, K: 10.315, being 2.03, 1.73 and 1.34 times as much as in the pure forest. As well, decaying leaves of Tsoong' tree accounted for 48.80% N, 47.83% P and 22.41% K, respectively, in the mixed forest which

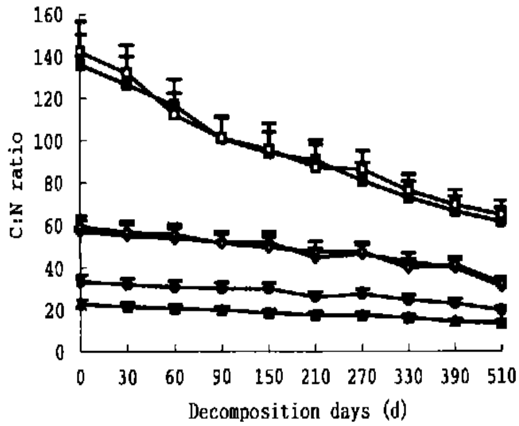

Fig. 3 Changes of C:N ratios in various litter groups during 510 days of decomposition

suggested that Tsoong' tree leaves played an important role in total nutrient release.

3 Discussion

3.1 Decomposition

Several authors have reported that the substrate quality (e.g. content of lignin, nitrogen and C: N ratios) can exert a profound influence on the decay rate (Melillo *et al.*, 1982; Harmon *et al.*, 1990). The rapid dry matter disappearance at the initial stage of decomposition could be explained as the loss of readily decomposable carbohydrates, while the relatively slow decomposition during the later decay period might be attributed, in part, to the accumulation of the decay-resistant materials such as lignin and cellulose. The higher coarse protein and lower lignin contents in Tsoong' tree leaves compared with Chinese fir needles can be responsible for the high decomposition rate, while the reverse was true for branch litter of Chinese fir, which has the slowest decay rate due to its high lignin and cellulose content. High litter N contents have generally been considered to increase decomposition rates, and a positive correlation between litter decay rates and N contents has been reported in many studies (eg. Flanagan & van Cleve, 1983; Enriquez *et al.*, 1993). In addition, the C:N ratios were mostly related to the litter mass loss in the early stage (Taylor *et al.*, 1989). Fig. 1 and Fig. 3 showed that the litter components which had the higher initial C:N ratio had the slower decomposition rate. The relationship between lignin concentration and decomposition rates has also been studied recently (Gallardo & Merino, 1993). Lignin is an interfering factor in the enzymatic degradation of cellulose and other carbohydrates, as well as proteins. High initial levels of lignin may thus slow decomposition rates. The annual decomposition rates of the aboveground litters were relatively lower as compared to those of fine roots (< 2 mm in diameter) in the same research sites (60.5%-63.3% for Chinese fir, 87.8%-92.2% for Tsoong's tree)[1). This is largely due to the higher substrate quality of fine roots than that of aboveground litter.

1) Chen, G. S. (陈光水). 2001. Studies on ecology of fine roots in the community of mixed forest of Chinese fir and *Tsoongiodendron odorum*. Nanping: The postgraduate thesis of Fujian Agriculture and Forestry University. (in Chinese)

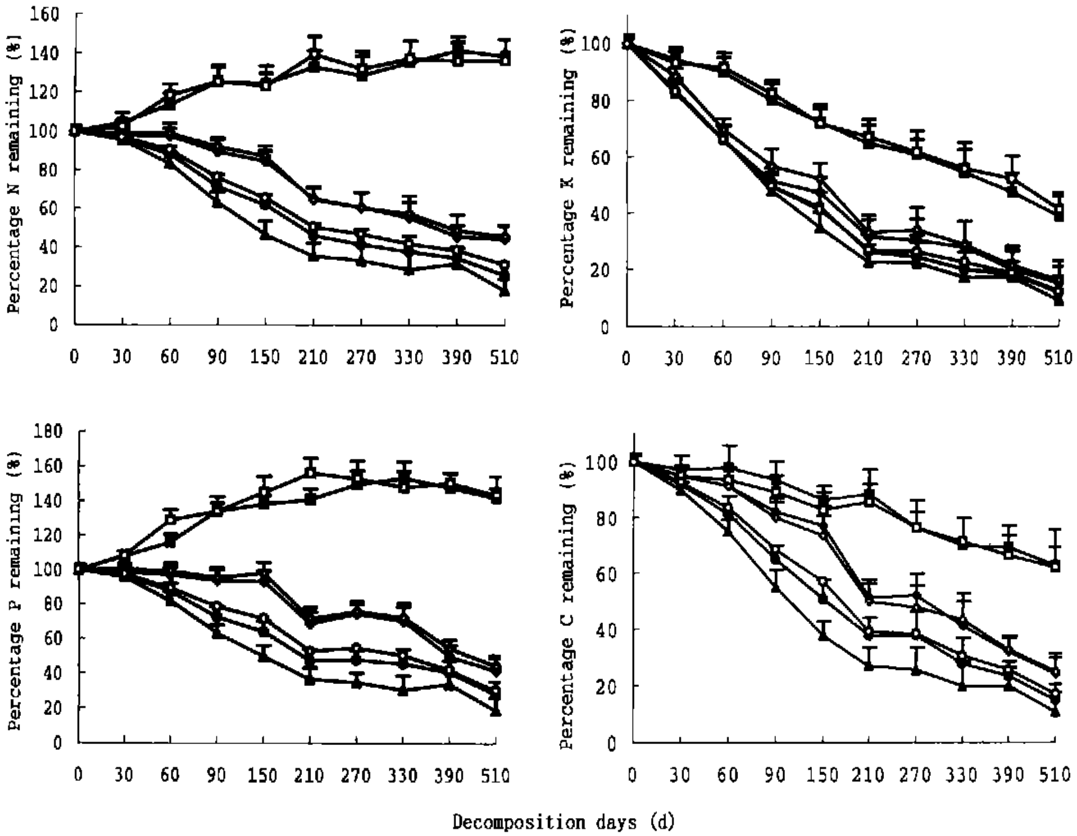

Fig.4　Percentages of N, P, K and C remaining in various litter groups during 510 days of decomposition

Table 2　Nutrient release rates of various litter components in the mixed and pure forests (%)

Forest type	Litter component	Items	C	N	P	K
Mixed forest	Chinese fir needle	Nutrient remaining rate after 510 days	23.98	44.36	41.77	15.35
		Release rate of the first year	62.17	45.77	41.73	77.14
	Chinese fir branch	Nutrient remaining rate after 510 days	62.79	Accumulation	Accumulation	38.83
		Release rate of the first year	27.67	Accumulation	Accumulation	49.54
	Tsoong' tree leaf	Nutrient remaining rate after 510 days	10.67	18.01	18.92	9.31
		Release rate of the first year	81.58	72.64	70.59	84.05
	Mixed leaves	Nutrient remaining rate after 510 days	15.12	25.78	28.13	11.96
		Predicted value	17.325	31.185	30.345	12.33
		Release rate of the first year	74.54	64.80	59.34	81.58
Pure forest	Chinese fir needle	Nutrient remaining rate after 510 days	25.273	45.871	44.574	16.284
		Release rate of the first year	62.17	45.77	37.37	75.44
	Chinese fir branch	Nutrient remaining rate after 510 days	62.192	Accumulation	Accumulation	41.288
		Release rate of the first year	30.23	Accumulation	Accumulation	47.69

In addition, the rate of litter decomposition was influenced by a number of extrinsic factors including soil moisture, temperature, and the nature of soil microorganisms and fauna during the decomposition process. McClaugherty *et al.* (1985) suggested that the differences in temperature, moisture conditions and their interactions, and the activity of the decomposer could, to a great extent, explain the large variations in the litter decomposition rates. The activity of microorganisms mainly depends on the substrate N availability. However, if relatively large amounts of exogenous nitrogen are available to the microorganisms during litter decomposition, then initial nitrogen content of the litter may not exert so great an influence on decomposition rates, and lignin content may become more significant in determining the decomposition rates.

Our results for litter decomposition rates of Chinese fir were in the range of those reported elsewhere. Tian *et al.* (1989b) found that in Huitong the decomposition rates of the leaf and branch of a 22-year-old Chinese fir

Table 3 Annual nutrient return and release in various litter components in the mixed and pure forests (kg·hm^{-2}·a^{-1})

Forest type	Element	Item	Chinese fir needle	Chinese fir branch	Tsoong' tree leaf	Total	Release/return ratio (%)
Mixed forest	N	Annual return	20.049	4.827	12.039	36.915	48.55
		Annual release	9.176	0	8.745	17.921	
	P	Annual return	0.893	0.200	0.485	1.578	45.31
		Annual release	0.373	0	0.342	0.715	
	K	Annual return	8.789	2.469	2.751	14.009	73.63
		Annual release	6.780	1.223	2.312	10.315	
Pure forest	N	Annual return	19.291	6.040		25.331	34.85
		Annual release	8.829	0		8.829	
	P	Annual return	1.105	0.283		1.388	29.76
		Annual release	0.413	0		0.413	
	K	Annual return	8.912	2.055		10.967	70.24
		Annual release	6.723	0.980		7.703	

were 48.2% and 21.9%, respectively; after the first year, the corresponding values were also reported as 33.03% and 20.91% for an 18-year-old Chinese fir in Laoshan of Guangxi (Liang, 1993), and 39.73% and 24.87% for a young Chinese fir plantation in Youxi of Fujian (Ma *et al.*, 1997). In addition, the decomposition rate of the integrated litter of Chinese fir was also reported, e.g. 20% in Wu *et al.* (1990) and 54% in Chen *et al.* (1988).

The decomposition rates of leaves of broad-leaved trees are frequently reported from the subtropics. Wu *et al.* (1990) reported that the leaf decay rates were 57.6% for *Schima vallichii* and 50.5% for *Firmiana simplex* in southern sub-tropics. A high value of 95% was reported by Chen *et al.* (1988) for *Michelia macclurei* in Huitong, Hunan Province. Chen (1992)[1)] examined the leaf decomposition rates of the associated broadleaves in natural Chinese fir forest in Wuyi Mountain and found the values were: *Castanopsis eyrei* 71.6%, *C. fargesii* 67.1%, *Phyllostachys pubescens* 66.3%, *Castanopsis carlesii* 64.4%, *C. sclerophylla* 58.9%, *Schima superba* 55.6%. Tu *et al.* (1993) reported the values for several broad-leaved trees in Dinghu Mountain as follows: *Castanopsis chinensis* 57%, *Cryptocarya chinensis* 42%, *C. concinna* 54% and *Schima superba*, 54%. It can also be seen that the leaf decomposing rate for *T. odorum* in our study was not outside the ranges reported for broad-leaved tree species in subtropics.

Furthermore, the decomposition rate for needle of Chinese fir was comparable to the leaf decay rates of most broad-leaved tree species. The relative rapid decomposition for Chinese fir needles in the present study was perhaps surprising since Chinese fir has been frequently criticized for its low litter decomposition rate that was partly responsible for the soil degradation in plantations with continuous monoculture of Chinese fir. A further study should be conducted to verify the extent to which the inherent characteristics of Chinese fir modify the soil nutritional status.

We also proposed a linear decaying model to estimate the litter decay rate relating the values of annual litter input to the litter mass on the forest floor. The model requires two prerequisites: both the amounts of litter input and the decay rate at any time interval are steady. Then at the end of a turnover period (n), the remaining weight (m) of the litter input (y) at the time of t in this turnover period is:

$$m = y\left(1 - \frac{n-t}{n}\right) = \frac{yt}{n} \quad (1)$$

The accumulative remaining weight of litterfall (M) at the end of a turnover period is then:

$$M = \int_0^n m = \int_0^n \frac{yt}{n} = \frac{yn^2}{2n} = \frac{yn}{2} \quad (2)$$

Thus, the turnover period (n) and the decay rate (R) can be calculated as follows:

$$n = \frac{2M}{y} \quad (3)$$

$$R = \frac{1}{n} = \frac{y}{2M} \quad (4)$$

The estimated values from this model are listed in Table 4. The values for needles and branches of Chinese fir were similar to those estimated from litterbag decomposition, while that for leaf of Tsoong's tree was surprisingly higher than that from the litterbag. The relative low decay rate in litterbag for leaf of Tsoong's tree might be due to the exclusion of some kinds of soil macro faunas, which consume the leaf litter of Tsoong's tree as their favorite food and do not consume the litter of Chinese fir.

3.2 Nutrient concentrations

Nutrient concentrations showed different trends of variations during the decomposing period and between litter components. Increases in N and P concentrations were largely due to microbial immobilization (O'Connell, 1988). Since these elements were either directly linked to

1) Chen, J. Y. (陈金耀). 1992. Nutrient accumulation and release in litterfall of some associated tree species in natural mixed forest of Chinese fir in Mountain Wuyi. Nanping: The postgraduate thesis of Fujian College of Forestry. (in Chinese)

Table 4 The turnover periods and decay rates obtained from the linear decay model

Forests fractions	Mixed forest			Pure forest	
	Chinese fir needle	Chinese fir branch	Tsoong' tree leaf	Chinese fir needle	Chinese fir branch
Litterfall ($g \cdot m^{-2}$)	255.0	115.4	89.9	303.3	127.2
Litter mass ($g \cdot m^{-2}$)	195.5	193.4	22.1	218.6	189.2
Turnover period (a)	1.53	3.35	0.49	1.44	2.98
Decay rate (%)	0.6521	0.2983	2.0330	0.6938	0.3361

carbon or were part of the structure of organic matter, they were released only when the carbon was consumed by heterotrophic microorganisms. These elements were retained gradually by organisms until a critical (suitable) concentration was reached, then release of these elements occurred. The decrease in K concentration might be due to the rapid leaching from the litter and the decrease of C concentration might result from consumption by organisms.

3.3 Nutrient release

The release of nutrients from decaying litter is essential to maintaining the fertility of forest soil. Patterns of nutrient release could be very different in litter types with a different structure or chemistry. Nutrient recycling often could occur in three sequential phases, including an initial nutrient release through leaching, a net immobilization of nutrients by decomposer microorganisms and nutrient release from the litter, usually at a rate paralleling mass loss. However, the pattern of immobilization and release varies among species and ecosystems, and any particular litter type may not show all three phases. In conifer needles and woody litter the leaching phase is small or absent, and the bulk of the release of N and P occurs through microbial metabolism of structural organic compounds (O' Connell, 1988). Moreover, nutrient dynamics are based on intrinsic features of the litter and the effects of extrinsic factors, such as nutrient availability.

In the litter bags filled with Chinese fir branches, the absolute amounts of N and P increased, which was attributed to accumulation of these elements. The degree of accumulation differed and was dependent on the initial concentration in the litter bags (Fig. 4). In general, accumulations of N and P would take place in tissues with C:N and C:P ratios greater than critical values (Killham & Foster, 1994). The branch litter of Chinese fir, with low initial N and P concentrations, had a very high initial C:N ratio (138); and even at the end of the study period, the C:N ratio of the remnants was still higher than 65. Thus N and P, which were continuously held by microbes during the study period, showed a large accumulation. While the leaf litter of Tsoong's tree showed a net release of N and P from the outset of the study. This suggests that floristic composition influences nutrient release pattern and magnitude in a substantial manner, and a great deal of nutrients were released in the mixed forest.

According to the results of this same study, nutrient release from fine roots of trees in the mixed forest, expressed as $kg \cdot hm^{-2} \cdot a^{-1}$, was N 10.325, P 0.778 and K 11.764, representing 57.61, 108.81, and 114.05 percent of the amounts released from aboveground litterfall, respectively. The comparative importance of annual release of P and K from fine roots can be seen. Thus, precise measurements of annual nutrient release in forest ecosystems should include those from fine roots; otherwise, the values would be highly underestimated.

Litter decomposition is an important process for nutrient recycling in forest ecosystems. Slow rates of litter decomposition can result in large amounts of nutrients held in the litter mass on the forest floor that is unavailable to plants. It can be seen from Table 2 that the annual nutrient return and release was far from balanced, especially for N and P, with only 34.85% of annual N return and 29.76% of annual P return released for pure forest in the first year. This was disadvantageous to the reuse of nutrients by plantation trees, particularly for pure Chinese fir forest, which has been considered as a cause to the soil degradation in its monoculture. However, this was challenged in view of little annual litter accumulation on the forest floor of pure Chinese fir forest and the comparable decay rate of Chinese fir leaf litter to that of broadleaved tree species as mentioned above. What went wrong? Before attempting to answer this, maybe a method of estimating decomposition more accurate than the litterbag technique should be used and long-term decomposition data should be collected in future studies.

4 Conclusions

In the mixed forest of Chinese fir and Tsoong' tree, leaf litter mass disappearance rates in the litterbags differed significantly among various litter components. Tsoong' tree leaves were characterized by a faster rate of decomposition. Substrate quality, notably, the initial nitrogen content and C:N ratios, as a major regulatory factor had a marked effect on litter decay rates and nutrient release to the soils. Mixing Chinese fir needle and *T. odorum* leaf commonly stimulated mass loss and nutrient release. Annual nutrient release from litterfall of mixed forest were greater than that of pure forest. Thus, introducing broadleaved trees into Chinese fir plantations could produce complex litterfall and hence enhance the within-stand nutrient cycling rate by means of speeding nutrient release during decomposition.

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