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格氏栲天然林与人工林凋落叶分解过程中养分动态

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摘要: 通过对中亚热带格氏栲天然林（natural forest of *Castanopsis kawakamii*，约150a)、格氏栲和杉木人工林（monoculture plantations of *C. kawakamii* and *Cunninghamia lanceolata*, 33年生）凋落叶分解过程中养分动态的研究表明, 各凋落叶分解过程中N初始浓度均发生不同程度的增加后下降; 除格氏栲天然林中其它树种叶和杉木叶P浓度先增加后下降外, 其它均随分解过程而下降; 除杉木叶外, 其它类型凋落叶的Ca和Mg浓度呈上升趋势; 凋落叶K浓度均随分解过程不断下降。养分残留率与分解时间之间存在着指数函数关系 $x_t = x_0e^{-kt}$。凋落叶分解过程中各养分释放常数分别为: N（k_N）0.678～4.088; P（k_P）0.621～4.308; K(k_K）1.408～4.421; Ca（k_{Ca}）0.799～3.756; Mg（k_{Mg}）0.837～3.894。除杉木叶外, 其它凋落叶分解过程中均呈 $k_K > k_P > k_N > k_{Mg} > k_{Ca}$ 的顺序变化。各林分凋落叶的年养分释放量分别为N 10.73～48.19kg/(hm^2·a), P 0.61～3.70 kg/(hm^2·a), K 6.66～39.61kg/(hm^2·a), Ca 17.90～20.91kg/(hm^2·a), Mg 3.21～9.85kg/(hm^2·a)。与针叶树人工林相比, 天然阔叶林凋落叶分解过程中较快的养分释放和较高的养分释放量有利于促进养分再循环, 这对地力维持有重要作用。

关键词: 养分释放; 分解; 凋落叶; 格氏栲; 杉木; 天然林; 人工林

Nutrient dynamics of decomposing leaf litter in natural and monoculture plantation forests of *Castanopsis kawakamii* in subtropical China

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Abstract: Nutrient dynamics of decomposing leaf litter was studied in two 33-year-old plantations, Chinese fir (*Cunninghamia lanceolata*, CF) and *Castanopsis kawakamii* (CK), and compared with that of an adjacent natural forest of *Castanopsis kawakamii* (NF, ～150 year old) in Sanming, Fujian, China. During the decomposition, varying degree of initial increase followed by decrease of N concentrations was observed in leaf litter, while initial increase and then decrease of P concentration was only found in leaves of other tree species in the NF and Chinese fir needle. The concentrations of Ca and Mg increased in all leaves except for Chinese fir needle, whereas that of K decreased consistently. Using the model $x_t = x_0e^{-kt}$, the decay constants of nutrients ranged from 0.678 to 4.088 for N (k_N), from 0.621 to 4.308 for P (k_P), from 1.408 to 4.421 for K (k_K), from 0.799 to 3.756 for Ca (k_{Ca}) and from 0.837 to 3.894 for Mg (k_{Mg}) respectively. The decay constants of nutrients during leaf-litter decomposition can be arranged in the sequence of $k_K > k_P > k_N > k_{Mg} > k_{Ca}$, except for leaf litter of Chinese fir where $k_K > k_{Mg} > k_{Ca} > k_N > k_P$. Annual nutrient release from decaying leaf litters in the three forests was N, 10.73～48.19 kg/(hm^2·a); P, 0.61～3.70 kg/(hm^2·a); K, 6.66～39.61 kg/(hm^2·a); Ca, 17.90～20.91 kg/(hm^2·a) and Mg, 3.21～9.85 kg/(hm^2·a) respectively. It was concluded that faster nutrient release of leaf litter and its greater amount in the natural broadleaved forest were beneficial to nutrient recycling and soil fertility maintenance than monoculture coniferous plantations.

Key words: nutrient release; decomposition; leaf-litter; *Castanopsis kawakamii*; *Cunninghamia lanceolata*; natural forest;

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1 Introduction

Forest litter acts as an input-output system of nutrients and its decays contribute to the regulation of nutrient cycling as well as soil fertility and primary productivity in forest ecosystems[1~4]. Thus, it is critical to understand the nutrient return and corresponding nutrient release from litter in these forest ecosystems[1, 5]. Despite a wealth of information on litter decomposition dynamics in different forest ecosystems of the world has been compiled, largely in temperate and tropical forests[1, 5~7], a relative few studies were carried out in forests of southern China, an area of the most important world subtropical forests

In southern China, where high rainfall, steep slopes, and fragile soil are characteristic, large-scale of native forests have been converted to monoculture plantations (mainly economical conifers) following forest land clear-cutting, slash burning, and soil preparation. Yield decline and land deterioration have become noticeable during this conversion, and how to maintain soil fertility in these managed plantations has received considerable attention[8~10]. Currently, difference in vegetation composition, soil fertility, litterfall amount and its nutrient return, fine root production and turnover between natural *Castanopsis kawakamii* forest and plantations have been examined[10~14]. The objective of this study was to determine nutrient release from decomposing leaf litter in two plantation forests of *Cunninghamia lanceolata* (Chinese fir, CF) and *C. kawakamii* (CK), and an adjacent natural forest of *C. kawakamii* (NF).

2 Materials and methods

2 1 Site description[12, 13]

The study sites were located in Xinkou Town, Sanming City, Fujian Province, China (26°11′30″N, 117°26′00″E). Site descriptions and stand characteristics and soil properties of the three studied forests, viz., plantation forest of *Cunninghamia lanceolata* (Chinese fir, CF), plantation forest of *C. kawakamii* (CK), and natural forest of *C. kawakamii* (NF), were detailed in references[12, 13].

2 2 Leaf-litter decomposition

The litterbag technique was used to quantify decomposition of leaf litter. In April 1999, freshly fallen/senescent leaves from *C. kawakamii* and other tree species in the NF and from tree species in two plantations were collected on nylon mesh screens for decomposition experiment Three sub-samples from each leaf-litter species were retained for the determination of initial chemical composition. Except for leaf-litter of single tree species of *C. kawakamii* in the NF and CK, and Chinese fir, leaves of other species of trees in the NF and mixed-leaf of equal amount of the individual *C. kawakamii* and other tree species in the NF were employed for decomposition experiment A known amount of air-dried leaf litter (20 g) of each species was put into a 20cm×20cm, 1.0 mm mesh size nylon bag For each type, 80 bags were prepared and randomly placed on the forest floor in the respective stands at the end of April 1999. After 30, 60, 90, 150, 210, 270, 330, 390, 510, 630, and 750 days after placement of samples, 6 litterbags were recovered at random from each forest site, and transported to the laboratory. The adhering soil, plant detritus and the "ingrowth" roots were excluded, and the bags were then dried at 80 ℃ to constant weight for the determination of remaining weight Sub-samples by species and date were reserved for the analysis of N, P, K, Ca and Mg concentrations

2 3 Chemical analyses

All oven-dried litter sub-samples were ground and passed through a 1mm mesh screen before chemical analysis For the determination of C, the plant samples were digested in $K_2Cr_2O_7$-H_2SO_4 solution using an oil-bath heating and then C concentration was determined from titration. For determination of N, P, K, Ca, and Mg, 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 with blue phospho-molybdate, K by flame photometry, and Ca and Mg concentrations were determined by the atomic absorption method[15]. The initial lignin concentrations of leaf litter samples were determined by the proximate chemical analysis[16]. All chemical analyses were carried out in triplicate on the same subsample.

2 4 Statistical analyses and calculations

The data on nutrient release after 750 days and initial chemical composition of fresh leaf-litter were analysed using a one-way ANOVA. The multiple comparisons were determined with the least significant difference (LSD) test at a significance level of 0.05[17]. Statistical analysis of data expressed as percentages was performed after square-root arcsine transformation.

The model for the loss of nutrients during the studied decomposition period is represented by the following equation[18]:

$$x_t = x_0 e^{-kt}$$

where x_t is the nutrient remaining at time t, x_0 is the initial nutrient content, the constant k is the decomposing coefficient, and t is the time. Correlation coefficients (r) between decay constants of nutrients and the initial chemical properties of leaf litter were also calculated.

3 Results

3.1 Nutrient concentrations in decomposing leaf litter

Varying degree of increase followed by decrease of N concentrations was observed in leaf litter (Fig. 1). At the end of one year, N concentration in needles of Chinese fir was still 135 % of the initial N concentration. In case of *C. kawakamii* in the NF the increase in N concentrations occurred only up to early 210 days and thereafter there was a sharp decline. There was a decreased trend in the C/N ratios for all leaf litters in the course of decomposition and the decreased degree was similar among these leaf litters (Fig. 2).

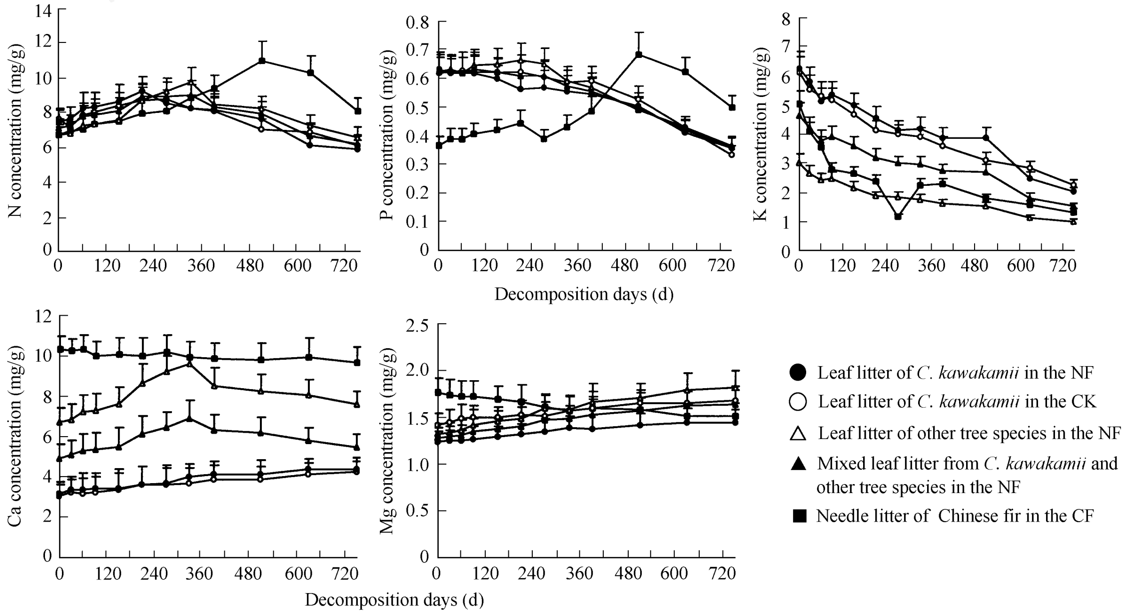

Fig. 1 Changes of relative concentrations of N, P, K, Ca and Mg in the various leaf litters over a 750 day period (Bars indicate + s. d., $n = 6$)

● Leaf litter of *C. kawakamii* in the NF ○ Leaf litter of *C. kawakamii* in the CK △ Leaf litter of other tree species in the NF ▲ Mixed leaf litter from *C. kawakamii* and other tree species in the NF ■ Needle litter of Chinese fir in the CF

P concentrations in leaves of *C. kawakamii* in the CK and NF and mixed leaves decreased during decay, while they relatively increased initially and then decreased in leaves of other tree species in the NF and Chinese fir needle (Fig. 1). The N/P ratios in needle litter of Chinese fir remained relatively constant until 210 days when there was a significant increase and then declined gradually from 270 days. Other leaf litters showed an increase in N/P ratios during the decomposition (Fig. 3).

Generally, K concentrations declined during decomposition for all leaf litter types (Fig. 1). The concentrations of Ca and Mg increased upon decomposition for leaves of *C. kawakamii* in the CK and NF, other tree species in the NF and mixed leaves, while the concentrations in decomposing Chinese fir needle showed a decrease with time. Initial Ca concentrations of leaves of *C. kawakamii* in the CK and NF were distinctly lower than in Chinese fir needle (Fig. 1).

3.2 Nutrient remaining rates of decomposing leaf litter

Considering N dynamics under all the stands, *C. kawakamii* leaf litter in the NF showed the highest net release (98.2% of initial N content in the first year), and Chinese fir the lowest one (Fig. 4). Decrease in P stocks in all leaf types reflects net mineralization of this nutrient from the beginning. However, throughout the decomposition period different degrees of increase in P stock was recorded for leaves of Chinese fir (Fig. 4). The tendency toward net release of K in all leaf litters was evident during the decomposition (Fig. 4). There was a decline in both the amounts of Ca and Mg in various leaf litters over time (Fig. 4). Losses of Ca and Mg were rapid in the first 150 days after which they were released slowly from *C. kawakamii* leaf litter in the NF and CK and mixed leaves. While leaves of other tree species in the NF and Chinese fir showed net mineralization of Ca and Mg gradually (Fig. 4).

The decay constant of N (k_N) ranged from 0.678 in Chinese fir to 4.088 in *C. kawakamii* in the NF; the decay constant of P (k_P) ranged from 0.621 for Chinese fir to 4.308 for *C. kawakamii* in the NF; and the decay constant of K (k_K) also ranged from 1.408 in Chinese fir to 4.421 in *C. kawakamii* in the NF (Table 1). The highest decay constants of Ca (k_{Ca}) and Mg (k_{Mg}) were 3.756 and 3.894 for *C. kawakamii* in the NF respectively (Table 1). The decay constants of nutrients during leaf-litter decomposition can be arranged in the sequence of $k_K > k_P > k_N > k_{Mg} > k_{Ca}$, except for leaf litter of Chinese fir where $k_K > k_{Mg} > k_{Ca} > k_N > k_P$ (Table 1).

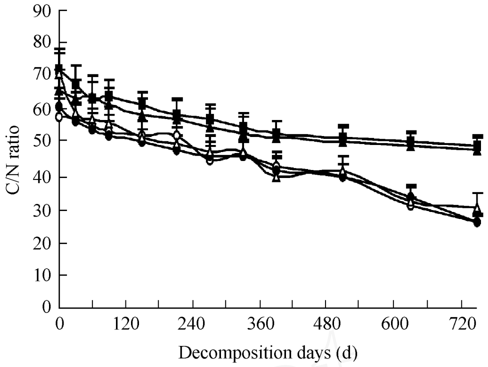

Fig. 2 Changes of C/N ratios in various leaf litter over a 750 day period. Same symbols as in Fig. 1. Bars indicate + s.d., $n=6$

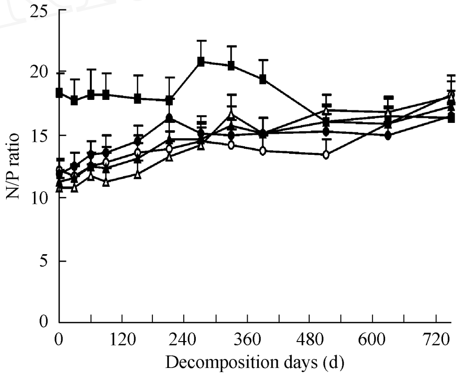

Fig. 3 Changes of N/P ratios in various leaf litters over a 750 day period (Same symbols as in fig. 1 Bars indicate + s.d., $n=6$)

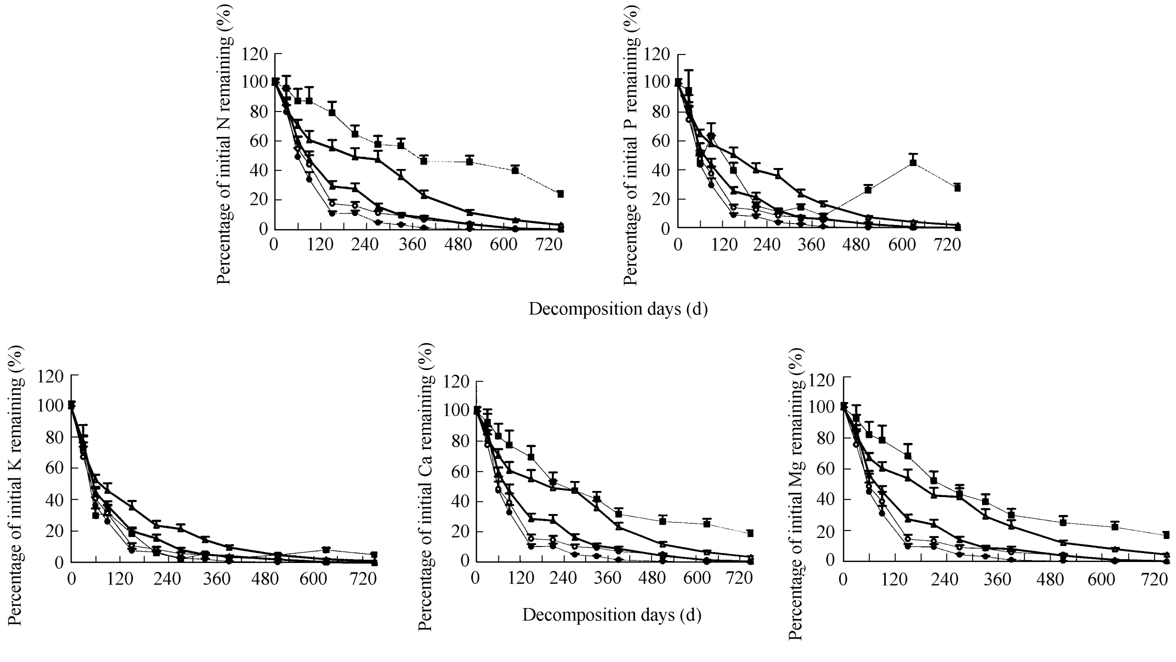

Fig. 4 Percentages of initial N, P, K Ca and Mg remaining in the various leaf litter over a 750 day period (Same symbols as in fig. 1. Bars indicate + s.d., $n=6$)

Table 1 The parameters of the decomposition models: $X_t = X_0 e^{-kt}$

Tree species	Nutrient contents									
	k_N	R_2	k_P	R^2	k_K	R^2	k_{Ca}	R^2	k_{Mg}	R^2
C. kawakamii in the NF	4.088	0.9923	4.308	0.9921	4.421	0.9907	3.756	0.9900	3.894	0.9907
Other tree species in the NF	1.604	0.9789	1.843	0.9872	2.111	0.9952	1.427	0.9691	1.594	0.9897
Mixed *C. kawakamii* and other tree species in the NF	2.583	0.9916	2.788	0.9936	3.061	0.9909	2.403	0.9915	2.464	0.9921
C. kawakamii in the CK	2.701	0.975	2.960	0.968	3.154	0.9703	2.506	0.9615	2.583	0.9619
Chinese fir	0.678	0.960	0.621	0.8062	1.408	0.9635	0.799	0.9725	0.837	0.9743

Notes: All regressions were significant at the 0.05 level

3.3 Nutrient release

Annual returns of N, P and K through leaf-litter in the NF and CK were significantly higher than those in the CF ($P < 0.05$). The CF returned the highest amount of Ca and the CK the lowest While the CK had the highest Mg returns through leaf litter (Table 2).

Annual nutrient release from decaying litter was determined by the nutrient decay rate and annual return of nutrients In the present study, 10.73～48.19 kg/(hm^2·a) N, 0.61～3.70 kg/(hm^2·a) P, 6.66～39.61 kg/(hm^2·a) K, 17.90～20.91 kg/(hm^2·a) Ca and 3.21～9.85 kg/(hm^2·a) Mg were released through leaf fall (Table 2). The CK had the highest releases of N, P, K and Mg from decomposing leaf litter. The leaf fraction of the NF released higher amounts of Ca than those of other two forests (Table 2).

Table 2 Annual nutrient return[12] and release (kg/(hm^2·a)) of N, P, K, Ca and Mg by leaf-litter in the three forests

Tree species	N		P		K		Ca		Mg	
	Annual return	Annual release	Annual return	Annual release	Annual return	Annual release	Annual return	Annual release	Annual return	Annual release
C. kawakamii in the NF	39.47	38.68	3.06	3.03	31.86	31.54	17.33	16.98	5.98	5.86
Other tree species in the NF	8.24	6.59	0.78	0.66	3.59	3.16	4.91	3.93	1.12	0.85
C. kawakamii and other tree species in the NF	47.71	45.27	3.84	3.69	35.45	34.7	22.24	20.91	7.1	6.71
C. kawakamii in the CK	51.82	48.19	3.89	3.70	41.26	39.61	20.84	19.17	10.71	9.85
Chinese fir	21.89	10.73	1.33	0.61	8.76	6.66	32.55	17.90	5.63	3.21

4 Discussion

4.1 Nutrient concentrations in decomposing leaf litter

Nutrient concentrations are known to vary to some extent during the decomposing period and between leaf litter types[2, 3, 19]. The increase in N concentrations (Fig. 1) followed by a decline over time as observed in this study is similar to the patterns found in other studies[2, 20]. The increases in N concentrations in decomposing leaf litter were due to mechanisms such as microbial immobilization of N, fungal translocation or insect frass[3], which resulted in a decrease in the C/N ratio of residues Chinese fir needle litter had a lower initial N concentration in comparison with other leaf litters and immobilized N over a longer period than other leaf litters (Fig. 1).

A concentration increase in the early stage of decomposition was also found in leaf litters of other tree species in the NF and Chinese fir for P, which was observed in some other studies[20～22]. It had been suggested that P immobilization, or an increase in P concentration occurred where P was limiting to microbial activity[3, 23]. Vogt *et al.* implied that C/P ratios determined whether P immobilization would occur[24]. Generally P immobilization occurred when the C/P ratio was high than 300[25]. Although initial C/P ratios in leaves of *C. kawakamii* in the NF and CK and mixed leaves remained higher than 300, their consistent decreases in P concentrations during 750 days were found. The regular critical C/P value could not be affirmed by our results, suggesting that critical C/P ratios might vary under different conditions[26].

K, as a monovalent cation, was weakly bound to the adsorption complex and the decrease in its concentration was restricted to the initial stage of decomposition, and could be attributed to leaching[3]. The clear increases of Ca and Mg concentrations in all leaf litter types except for Chinese fir needle were similar to the study by Van Wesemael[27] but different from the situation in some temperate forests[5].

4.2 Nutrient release from decomposing leaf litter

The high precipitation and temperature of subtropical climates yield a general high rate of nutrient release coupled with decomposition. Nutrient minerlization constants of the five leaf litters (Table 1, Fig. 4) were in the upper part of the range reported for the subtropics[28, 29]. Locally, the rates of nutrient release were mainly modified by differences in substrate quality[1, 21]. Since five leaf litter types in the present study were exposed to same climatic conditions, the between-type differences in nutrient release rates of leaf litters should relate to the substrate quality (Table 3). A negative exponential pattern for nutrient release from decomposing leaf litters was found (Table 1, Fig. 4), characterized by an initial rapid and a subsequent slow release phase, which was in agreement with the results reported by Jamaludheen and Kumar[3]. However, this pattern differed from the generalized tri-phasic model proposed by Berg and Staaf[30]. Rapid nutrient release in the earlier stage might be largely associated with leaching or mineralization of the soluble nutrient fraction, while the relatively slow nutrient release in the later stage is perhaps due to the binding of nutrient element to lignin or polyphenolics in the leaves[1, 23].

Table 3 Initial chemical composition of various leaf litter types

Composition (mg/g D.M.)	*C. kawakamii* in the NF	Other tree species in the NF	Mixed *C. kawakamii* and other tree species in the NF	*C. kawakamii* in the CK	Chinese fir
C	460±14ab	476±19ac	469±17a	444±9.7b	493±9.5c
N	7.5±1.4a	6.9±0.5a	7.1±0.5a	7.6±1.6a	6.8±1.6a
P	0.63±0.08a	0.62±0.05a	0.63±0.06a	0.62±0.07a	0.37±0.03b
Lignin	295±26a	309±27a	303±27a	301±25a	333±26a
C/N ratio	61	69	66	58	72
C/P ratio	730	768	744	716	1333
Lignin/N ratio	39	46	43	40	49

Notes: Values are means ±s.d., $n= 3$. Different letters on the same rows indicate significant differences ($P < 0.05$). D.M.: dry matter

Release of N began at once for all leaf litter types without net accumulation, suggesting that N was not a limiting factor for microorganisms because the initial N concentrations in these leaf-litters was relatively high compared to other studies[20, 21]. Initial N concentration of leaf litter was strongly positively correlated with k_N ($r = 0.838$, $P = 0.076$). While initial lignin concentration and lignin/N ratios showed significant negative correlations with k_N ($r = -0.911$, $P = 0.031$; $r = -0.951$, $P = 0.013$, respectively). Compared to lignin and lignin/N ratios, C/N ratio was also significantly but negatively related to k_N ($r = -0.815$, $P = 0.093$). Many previous workers also have found such negative relationships[6, 20, 21].

The P release patterns observed also demonstrate the importance of substrate quality on nutrient dynamics. P concentration and N/P ratio in the remaining leaf litter suggested that N dynamics might influence that of P, at least in the early stages of decomposition. The N/P ratio in fresh leaf litter of Chinese fir was higher compared with other leaf litters and showed a short immobilization phase. As 10 is the ideal N/P ratio for decomposers[24], the highest initial N/P ratio in the CF indicated that P could be more limiting in the leaf-litter decomposition in the CF than in other forests. Further, leaf litters except for Chinese fir needle maintained gradual increases of the N/P ratios throughout the decomposition, suggesting that nitrogen was controlling phosphorus dynamics. The three forests had low soil P availability[31] and thus P release from litterfall could play an important control of site productivity.

Among the nutrients, K had the most rapid rate of release (Table 1). Of the initial amount of K, 47%～70% was lost from decomposing leaf litter during the first 60 days compared with a weight loss of 16%～56%[12]; and the values of k_K were much higher than those of k[12] (Table 1). This indicated initial leaching loss of K because of its strong solubility. For all leaf litter types, net mineralizations of Ca and Mg occurred directly and the patterns of release were similar to those reported in other studies[19, 27]. The amount of Mg was lost at approximately the same rate as the dry weight[12], while relatively lower release rate of Ca than Mg was observed. The behaviour of the two elements was comparable with that in some mediterranean forests[27].

On an average, annual amounts of nutrient return and release of leaf litter in the NF were a little lower than those in the CK but significantly higher than in the CF (Table 2), which might be mainly related to the differences of absolute amount of leaf litter in three forests[12]. Further, greater litter (including fine roots) production[12, 13], a faster rate of nutrient mineralization associated with litter decomposition in the NF and CK compared to those in the CF indicated rapid recycling of nutrients within the systems and might be beneficial to improvements in soil fertility. Details regarding changes in soil nutrient status in the three forests are presented elsewhere[10].

5 Conclusion

Generally, broadleaved forests had higher amount and quality of litter coupled with greater nutrient returns[12] than coniferous ones *C. kawakamii*, not only in natural forest, but also in monoculture plantation, exhibited higher rate and greater amount of nutrient release from decomposing leaf litter than Chinese fir plantation. Substrate quality, such as initial concentrations of N and lignin, lignin/N and C/N ratios, showed significant correlations with nutrient mineralization constants of leaf litter. Especially leaf-litter of broadleaved trees had faster release of N compared with those of conifers. Chinese fir was found more P-limiting than other tree species in the leaf decomposition. Overall the higher returns and decay constants of N and P make the broadleaved trees more effective in release of these two nutrients than conifers, which indicates that broadleaved trees are more promising species instead of Chinese fir for afforestation, since N and P are the major limiting nutrients for most of subtropical forests of China.

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