Front. For. China 2009, 4(4): 450–457
DOI 10.1007/s11461-009-0062-y

RESEARCH ARTICLE

Hao ZHANG, Leeman CHU, Xueying ZHUANG

Decomposition of leaf litter of four native broad-leaved tree species in south China

© Higher Education Press and Springer-Verlag 2009

Abstract Leaf litter decomposition of *Castanopsis fissa*, *Cinnamomum camphora*, *Michelia macclurei* and *Mytilaria laosensis* in mixed broad-leaved plantation and pine plantation was studied by the litterbag method for 1 year. Leaf litter decomposition rates of the four species were highest in *Cinnamomum camphora*, followed by *Mytilaria laosensis*, *Michelia macclurei*, and *Castanopsis fissa*. The decomposition rates of all four species were higher in the mixed than in pine plantation. The decomposition processes of all species followed Olson's exponential model. The decomposition coefficients (k) of all species were also higher in the mixed plantation and had the same order as the decomposition rates. The nitrogen contents of leaf litter of the different species studied increased initially and then decreased with time. Net release of N only occurred in pine plantation. Potassium contents appeared to decrease first but later increase, and net release was only found in mixed plantation. Calcium, magnesium and boron all showed similar pattern of initial increase followed by later decrease. They all had net release in both mixed and pine plantations. The release of phosphorus varied greatly between species and showed no clear trend.

Keywords native broad-leaved trees, leaf litter, plantations, decomposition rate, nutrient release

1 Introduction

In terrestrial forest ecosystems, litter decomposition is not only an essential process of material cycling and energy flow but also plays an important role in maintaining ecosystem functions. Forest litter can provide most material and energy sources for soil decomposers and determine the soil nutrient supply, thereby affecting the nutrient uptake in plants (Adams and Angradi, 1996; Guo and Sims, 1999). In most ecosystems, more than 90% of the available nitrogen and phosphorus and more than 60% of mineral elements come from plant litter cycling (Chapin et al., 2002). The accumulation and decomposition of litter therefore determine nutrient flow and balance in forest ecosystems. So far, research mainly focused on factors affecting litter decomposition, mechanisms of nutrient release, efficiency of mixed decomposition and effects of increased CO_2 concentration on litter decomposition (Laskowski et al., 1995; Finzi and Schlesinger, 2002; Gartner and Cardon, 2004).

Masson pine (*Pinus massoniana* Lamb.) and slash pine (*Pinus elliottii* Engelm.) are the most common pioneer tree species in the revegetation of barren hills and degraded lands in southern China. It is well known that conifer litter decomposes slowly and acidifies soil environment, which inhibits microbial activities. Relatively speaking, broad-leaved species produce a more favorable environment for bacterial community because of the higher calcium content in their leaves (Gustafson, 1943). Planting with native broad-leaved species in conifer plantations is an effective approach to improve the structure and function of artificial plantations. Recently, more native tree species were planted in the Guangdong Province. Most studies to date have focused on native broad-leaved species selection and relevant planting techniques (Zhuang et al., 2001; Zhang et al., 2003) and ecological monitoring (Xue et al., 2002; Zeng et al., 2003), but there is a paucity of information on litter decomposition of broad-leaved species used in southern China. The species involved include some exotic species, such as *Acacia auriculiformis* A. Cunn. ex Benth., *Acacia mangium* Willd. and *Albizia falcataria* Fosberg., and some native broad-leaved species , such as *Schima superba* Gardn. & Champ., *Castanopsis fargesii* Franch., *Michelia macclurei* Dandy, *Fokienia hodginsii* Henry et Thomas and *Alnus cremastogyne* Burkill (Liao et al., 2000; Zhou and Yi, 2003; Yang et al., 2004).

Translated from *Acta Ecologica Sinica*, 2008, 28(5): 2395–2403
[译自: 生态学报]

Hao ZHANG, Leeman CHU
Department of Biology, the Chinese University of Hong Kong, Hong Kong, China

Xueying ZHUANG (✉)
College of Forestry, South China Agricultural University, Guangzhou 510642, China
E-mail: xyzhuang@scau.edu.cn

The objectives of this study are to assess the nutrient dynamics of litter of four broad-leaved species native to southern China and to compare their rates of decomposition in mixed broad-leaved plantation and slash pine plantation. The findings obtained can provide valuable information for practitioners involved with ecological forest construction and management in southern China.

2 Materials and methods

2.1 Study sites

The study sites were located in the arboretum of Changgang Hill (23°06′N, 113°18′E), South China Agricultural University, Tianhe District, Guangzhou. Guangzhou has a subtropical monsoon climate with a long summer and short winter. The annual mean, minimum and maximum temperatures are 21.8, 13.3 and 28.1°C, respectively. The mean annual precipitation is 1710 mm^3, about 80% of which fall in the six months of the year from April to September. The mean annual relative moisture was 79%. The study sites were low hilly woodland with an altitude of about 40 m. The zonal soil is acid Ultisol developed from granite according to USDA classification.

The experiment was carried out in a mixed plantation of *Schima superba* and *Michelia macclurei* and a pine (*Pinus elliottii*) plantation. The soil chemical composition of the two experimental sites is shown in Table 1.

2.2 Study methods

2.2.1 Sample collection

Newly fallen leaves of four broad-leaved species, namely *Castanopsis fissa* Rehd. et Wils., *Cinnamomum camphora* (L.) Presl., *Michelia macclurei* Dandy, and *Mytilaria laosensis* Lec., were collected from the study sites in early October 2003. The samples were air-dried at room temperature for about one week in the laboratory. In order to simulate the natural condition of litter, three-layer samples with similar bulk volume of the four species were put into nylon litterbags 28 cm×18 cm with 1 mm mesh, each containing 28 g of *Castanopsis fissa*, *Cinnamomum camphora* or *Mytilaria laosensis* or 14 g of *Michelia macclurei*.

2.2.2 Litterbag method

One 20 m transect was randomly set in the mixed broad-leaved tree plantation and pine plantation in early October 2003. The litterbags were buried in soil at a depth of 2 cm, at a distance of 0, 10 and 20 m along the transect. Four litterbags of each species were buried at each sampling point. One litterbag of each species at each sampling point was collected after 90, 180, 270 and 360 days and transferred to the laboratory for analysis.

2.2.3 Litter chemical analysis

The collected samples were rinsed with deionized water to remove roots and soil particles. The samples were weighed after drying at 60°C to constant weight to calculate the rates of weight loss and decomposition.

The samples were ground into powder and stored in plastic bags for chemical analysis. N and P were determined by micro-diffusion diffusion method, molybdenum blue method and flame photometry, respectively, after semi-micro Kjeldahl digestion H_2SO_4. K, Ca and Mg were determined by atomic absorption spectrophotometry after HF-$HClO_4$ (1∶1) digestion for K and dry ashing for Ca and Mg. B was determined using curcumin colorimetric method after hot water extraction (Department of National Forestry Criteria of PRC, 1999).

2.2.4 Decomposition rate and model

The decomposition rate was calculated using the following formula (Olson, 1963):

$$D_{WT}=(\Delta W/W_O)\times 100\%$$

where D_{WT} is the decomposition rate, ΔW is the loss of weight (g) between each collected sample and the original sample and W_O is the original litter weight.

Decomposition coefficient (k) was calculated using the exponential model as follows:

$$x/x_o= \exp^{(-kt)}$$

where x is the litter weight after a time t, x_o is the original litter weight and t is decomposition time.

3 Results

3.1 Decomposition rate and model of four species in two plantations

Litter weight loss of the four species followed similar trends in both mixed broad-leaved tree plantation and pine plantation. *Cinnamomum camphora* lost weight fastest, and *Castanopsis fissa* lost weight slowest. The decomposition

Table 1 Soil chemical composition of the two experimental sites

types	pH (1∶2.5)	organic C /(g·kg^{-1})	total N /(g·kg^{-1})	total P /(g·kg^{-1})	total K /(g·kg^{-1})	available N /(mg·kg^{-1})	available P /(mg·kg^{-1})	available K /(mg·kg^{-1})
mixed plantation	3.92	37.8	1.08	0.26	3.89	94.5	1.57	20.1
pine plantation	4.10	29.5	0.99	0.21	4.96	75.6	1.97	17.0

rates of the four species were in general faster in mixed broad-leaved tree plantation than in pine plantation (Fig. 1).

Using the exponential model to simulate the process of litter decomposition, the decomposition coefficients ($R^2 > 0.9$, $P < 0.05$) of the four species were high in the two plantations. The decomposition coefficients (k) of all four species were higher in the mixed broad-leaved plantation than in the pine plantation. Speed of decomposition followed the order *Cinnamomum camphora* > *Mytilaria laosensis* > *Michelia macclurei* > *Castanopsis fissa* (Table 2). According to the model, the time required for 50% litter breakdown of *Mytilaria laosensis* and *Cinnamomum camphora* was less than 1 year in mixed broad-leaved forest and less than 1.5 years in pine plantation. However, the time required for *Michelia macclurei* and *Castanopsis fissa* were 1 and 1.58 years in mixed forest and 1.48 and 2.24 years in pine plantation, respectively. Similarly, the time required for 95% litter decomposition of *Mytilaria laosensis* and *Cinnamomum camphora* was less than 4 years in mixed forest and about 5 years in pine plantation, whereas *Michelia macclurei* and *Castanopsis fissa* needed 4.3–9.7 years respectively.

3.2 Major nutrient contents of newly fallen litter

The contents of major nutrient in newly fallen litter of the four species are shown in Table 3. The contents of N, Ca and Mg were higher in litter of *Mytilaria laosensis* and *Cinnamomum camphora* than in that of *Michelia macclurei* and *Castanopsis fissa*. The litter of *Cinnamomum camphora* had the highest N, Ca, K and Mg, while *Mytilaria laosensis* had the highest B. The litter of *Michelia macclurei* had the lowest N, P, K and Mg and *Castanopsis fissa* had the lowest Ca and B. The ranking of nutrients for the litter of the four species was different. The nutrients of litter for *Michelia macclurei* were in the order of N > Ca > K > P > Mg > B. *Mytilaria laosensis* and *Castanopsis fissa* had similar ranking of N > Ca > K > Mg > P > B, whereas that for *Cinnamomum camphora* was Ca > N > K > Mg > P > B.

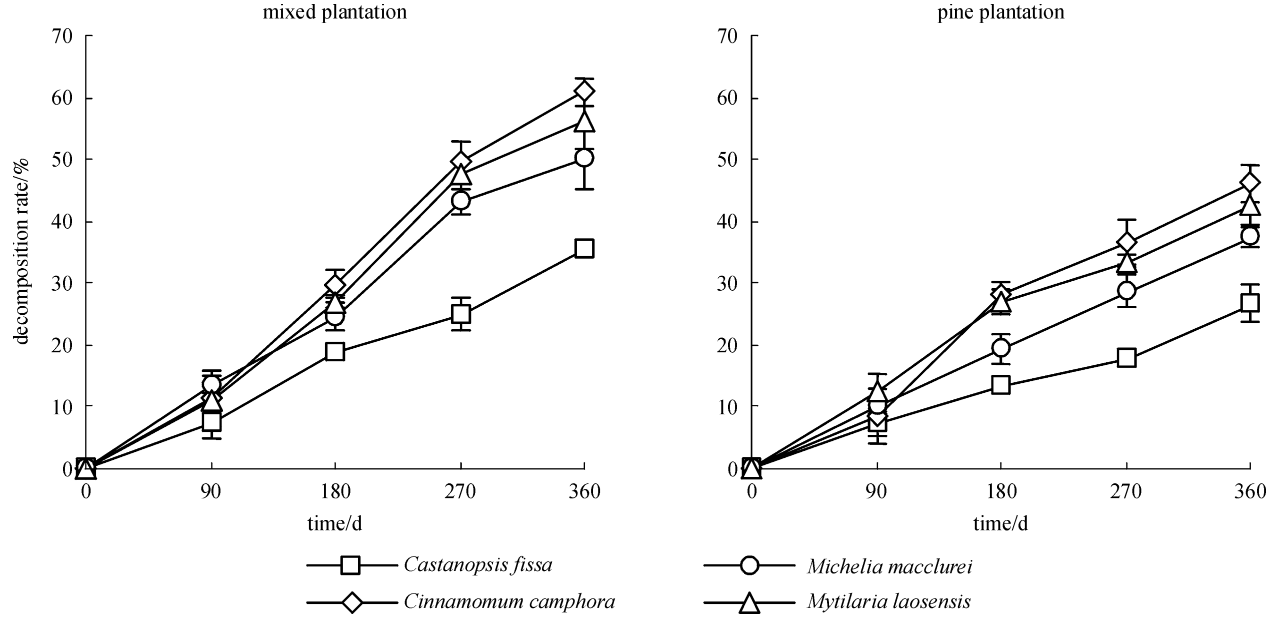

Fig. 1 Weight loss percentages of dry matter of the four species in two plantation sites

Table 2 Litter decomposition modes of the four species in the two plantation sites

vegetation types	tree species	decomposition coefficient k	determination rate R^2	50% breakdown time /year	95% breakdown time /year
mixed broad-leaved plantation	*Castanopsis fissa*	0.44±0.07	0.971	1.58	6.28
	Cinnamomum camphora	0.94±0.12	0.945	0.73	3.18
	Michelia macclurei	0.69±0.01	0.963	1.00	4.33
	Mytilaria laosensis	0.83±0.05	0.946	0.83	3.61
pine plantation	*Castanopsis fissa*	0.31±0.02	0.975	2.24	9.69
	Cinnamomum camphora	0.62±0.06	0.969	1.12	4.84
	Michelia macclurei	0.47±0.05	0.984	1.48	6.40
	Mytilaria laosensis	0.56±0.05	0.985	1.24	5.35

Table 3 Nutrient contents of newly fallen leaf litter of the four study species

species	N/(g·kg^{-1})	P/(g·kg^{-1})	K/(g·kg^{-1})	Ca/(g·kg^{-1})	Mg/(g·kg^{-1})	B/(g·kg^{-1})
Castanopsis fissa	8.91	0.86	4.90	5.85	0.91	21.8
Cinnamomum camphora	11.7	0.83	6.15	29.2	1.48	22.1
Michelia macclurei	8.42	0.64	2.50	8.35	0.49	23.0
Mytilaria laosensis	11.3	0.69	3.72	10.5	1.39	30.5

3.3 Changes in weight loss of litter nutrients

The weight loss dynamics of litter nutrients reflect the return of nutrients into natural cycles after physical and chemical decomposition at different times. There were remarkable differences in the changes in litter concentrations of the various nutrients, especially for N, P and K, with time in different species (Figs. 2 and 3).

The trends of N release for the four species in the two plantations were similar (Fig. 2). N was accumulated in the early decomposition period but was released at a later stage. N had no net annual loss for litter in the mixed broad-leaved forest, but net release occurred in the pine plantation after 270 days. Litter of *Castanopsis fissa* and *Cinnamomum camphora* released N earlier in pine plantation than in mixed broad-leaved forest. In one whole year, K had net release for the litter of the four species in mixed forest. However, in pine plantation, K had net release only before 180 days, after which K was accumulated and exceeded the original value.

The release of P from litter of the four species was not obvious. In the mixed plantations, P was released initially, then accumulated and released again for *Michelia macclurei* and *Castanopsis fissa*, with a net release before 180 days. However, *Mytilaria laosensis* and *Cinnamomum camphora* showed initial accumulation and subsequent release and accumulation, resulting in no net release in an entire year. In the pine plantation, *Michelia macclurei*, *Mytilaria laosensis* and *Cinnamomum camphora* showed different patterns of fluctuation from that of *Castanopsis fissa* with all species, except *Mytilaria laosensis* having net P release in a whole year.

The releasing trends of Ca, Mg and B of the four species in the two plantations were very similar (Fig. 3). They were accumulated to a lesser extent and then excessively released. There were net releases of Ca, Mg and B in the four species on an annual basis.

4 Discussion

4.1 Factors influencing litter decomposition

The weight loss of litter was affected by soil temperature, moisture and available nutrient contents, and by the texture and organic contents of the litter (Berg et al., 1993). Otsuki et al. (2005) suggested that soil moisture and temperature in natural oak forest were significantly higher than in pure plantation of *Robinia pseudoacacia*, which resulted in a higher decomposition rate of litter in broad-leaved forest. Mixed broad-leaved forest and pine plantation were chosen in this study. According to the results of soil chemical analysis, organic matter, total N and P and available N and K were higher in mixed forest than in pine plantation; only total K and available P were higher in the pine plantation. The litter decomposition rate was more rapid in mixed forest than in pine monostand, indicating that the former better supported litter decomposition and nutrient cycling. This is in line with another study in Yunnan pine plantation and evergreen broad-leaved forest (Liu et al., 2000). Microbes are the major decomposers in soil, and their activities are directly influenced by soil temperature, moisture and nutrient availability. Compared with pine plantation, mixed broad-leaved forest had more complex structure and abundant litter which could provide better growth conditions for soil microbes and animals, thereby accelerating litter decomposition.

The decomposition processes of all species followed Olson's exponential model. According to this model, the time required for 95% litter breakdown of the four species was 3 to 6.3 years in mixed plantations. *Cinnamomum camphora* had the fastest decomposition rate, requiring a period of 3.18 years (Table 2). This was similar to the estimated time of 2.5 to 4.5 years required for 95% litter breakdown of *Castanopsis sieboldii*, *Schima wallichii*, *Elaeocarpus japonicus* and *Daphniphyllum teijsmannii* in evergreen broad-leaved forest of Okinawa, Japan (Alhamd et al., 2004) but higher than 1.27 years for 95% litter breakdown in natural *Quercus* forest in subtropical India (Pandey et al., 2007). The time required for 95% litter breakdown of four species was 4.84–9.69 years in pine plantation, which was higher than 3.02–4.22 years for those of *Cunninghamia lanceolata* and *Michelia macclurei* in both mixed and pure *Cunninghamia* plantation in southern China (Wang et al., 2007). The annual decomposition rates of the four species ranged from 22.6% to 60.9%, which was lower than the 70% in the *Cryptocarya concinna* community in Dinghu Mountain or rainforests in tropical area (Weng et al., 1993), but higher than those (20–30%) in temperate forests (Hu et al., 1987). However, since this study only lasted for 1 year, the decomposition rates of litter from various species native to southern China need further investigation.

The quality of litter had a significant effect on the

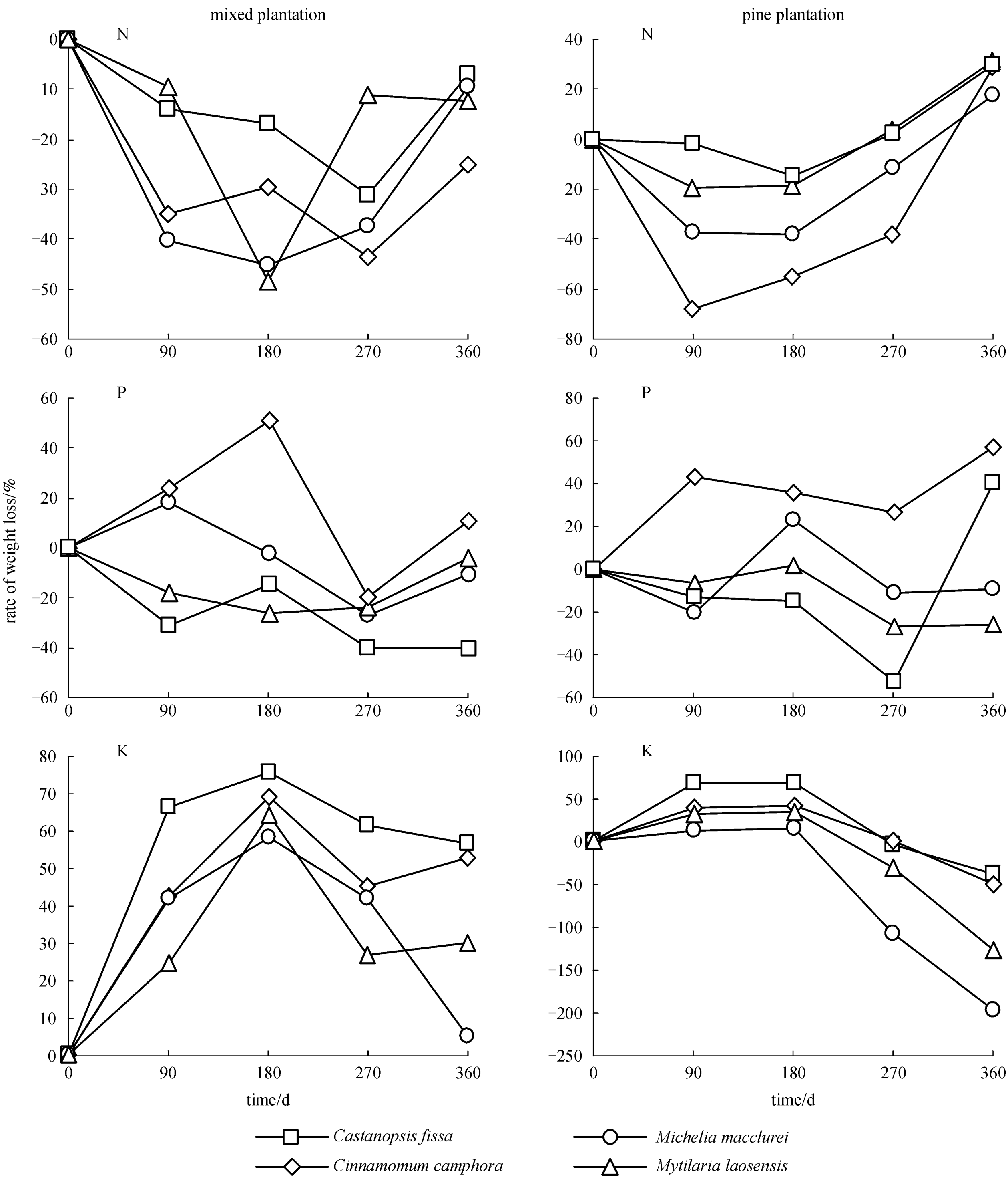

Fig. 2 Variations of N, P and K concentrations in leaf litter of the four species in two plantation sites

decomposition rate. Soil microbes, which require nutrients such as N and P, play an important role in litter decomposition. When the litter is rich in major nutrients, the growth of the soil microbial community increased rapidly, speeding up the decomposition rate (Enriquez et al., 1993). It is commonly believed that a positive correlation exists between the litter contents of N, P, K and Mg and the decomposition rate, which alters with the different decomposition stages (Angelis et al., 2000). It is well documented that decomposition rate was more rapid in high N litter than in low N litter (Mfilinge et al., 2002; Alhamd et al., 2004). Litter of *Mytilaria laosensis* and

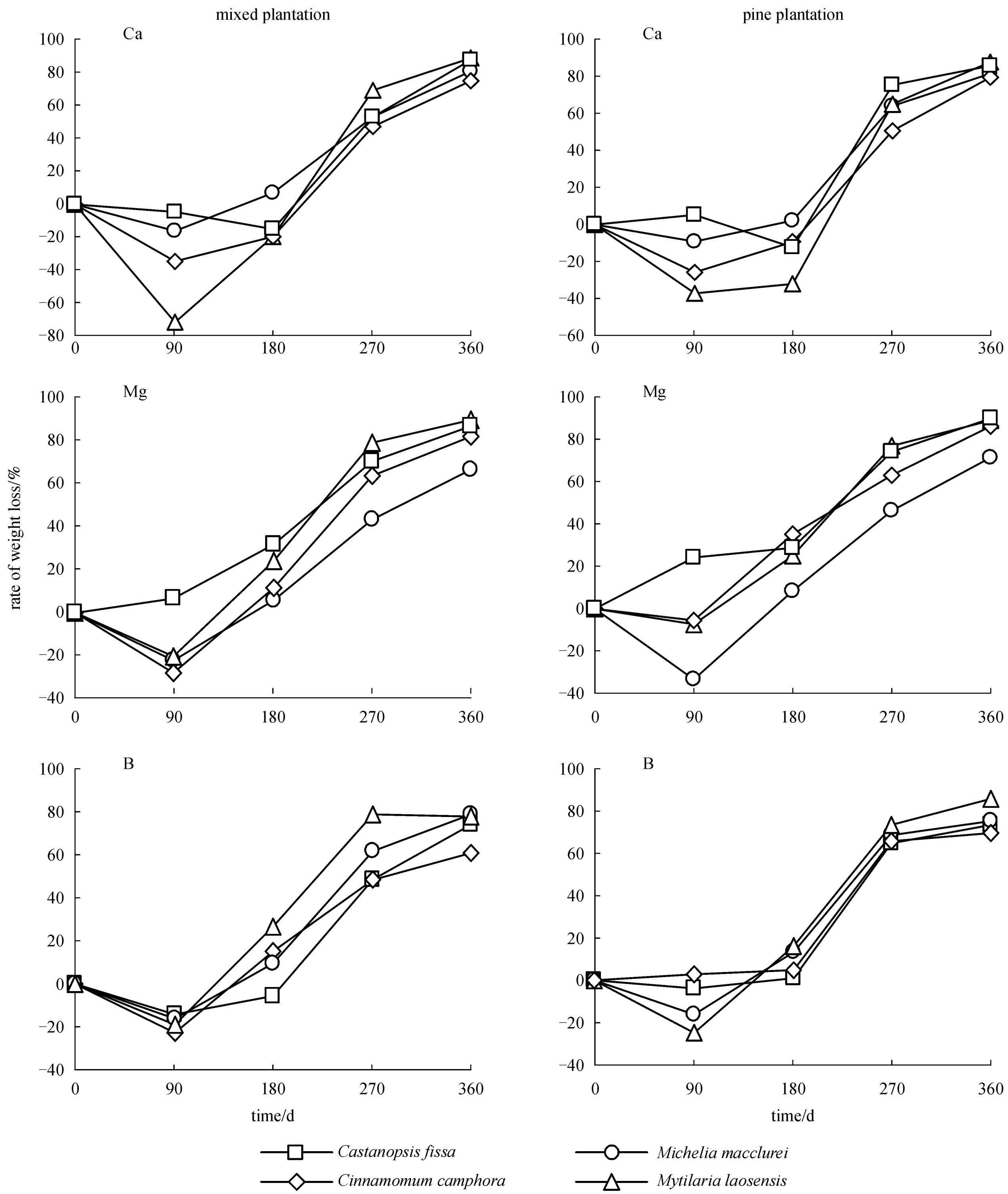

Fig. 3 Variations of Ca, Mg and B concentrations in leaf litter of the four species in two plantation sites

Cinnamomum camphora had higher contents of N, Ca and Mg than *Michelia macclurei* and *Castanopsis fissa* (Table 3). This corresponds to the higher decomposition rate in *Mytilaria laosensis* and *Cinnamomum camphora* than *Michelia macclurei* and *Castanopsis fissa* in both mixed broad-leaved and pine plantations. This also applies to the decomposition coefficient *k*, which was in the order of *Cinnamomum camphora* > *Mytilaria laosensis* > *Michelia macclurei* > *Castanopsis fissa* (Table 2). *Castanopsis fissa*, which belongs to the family of Fagaceae, has been heavily planted in southern China because it is fast-growing and supports the presence of mycorrhizal fungi. In spite of this, the decomposition rate of its litter was slow, and inferior to those of *Falcataria moluccana*, *Acacia auriculiformis*, *Eucalyptus tereticornis* and *Schima superba* (Zou and Yi, 2003). The low decomposition rate is probably a consequence of the high cutin content in leaf, which was positively related to the residual litter content because cutin could prevent invasion of fungal hyphae and suppressed litter decomposition (Gallardo and Merino, 1993).

4.2 Nutrient dynamics of decomposing litter

There are three common patterns of nutrient transfer during litter decomposition. They are 1) eluviation, accumulation and release, 2) accumulation and then release and 3) direct release (Li and Chen, 2004). The patterns were different for macronutrients N, P and K but similar for other essential nutrients such as Ca, Mg and B. N was accumulated and then released in mixed broad-leaved forest and pine plantation, which was similar with the results for litter of *Populus tremula*, *Robinia pseudoacacia*, *Fokienia hodginsii*, *Cunninghamia lanceolata*, *Pinus yunnanensis*, *Cyclobalnopsis glaucoides* and *Castanopsis orthacantha* (Jia et al., 1998; Liu et al., 2000; Yang et al., 2004). N was largely influenced by biological factors. It was an essential element for the growth of soil microbial communities and was easily fixed by soil microflora, which could lead to effective accumulation during the process of decomposition. N was totally released for the four species in pine plantation, but mixed broad-leaved forest had no net N release. N accumulation is caused by an increase in cytoplasmic N in microbes (Aber and Melillo, 1980), found in large populations in mixed forest, which led to prolonged N accumulation and no net N release. K was released and then accumulated for four species in mixed and pine plantations. K exists as ions in plant cells and is highly mobile. K could be released through eluviation in the early decomposition of litter and was under greater influence by hydrological conditions in late decomposition stages, resulting in highly seasonal fluctuation (Osono and Takeda, 2004). K was totally released for the four species in mixed broad-leaved forest, but pine plantation had no net K release. Pine plantation with sparse canopy is easily eroded by heavy rain, which leads to the high eluviation and low accumulation for K, therefore resulting in net release. P was affected by physical, chemical and most importantly, biological factors (Laskowski et al., 1995). P had no evidential clear pattern in mixed and pine plantations for the four species, which indicates the complexity of P in the process of litter decomposition.

Guangdong Province is located in a subtropical area and its climate is warm and wet. Ca and Mg were low in forest soil because they are highly eluviating after mineral weathering. Natural soils in Guangdong are poor in B than in other micronutrients (Office of Soil Survey of Guangdong Province, 1993). A study of the changes of these three elements in the process of litter decomposition could provide useful information on the nutrient cycle in degraded hills in southern China. In this study, Ca, Mg and B slightly accumulated initially and was then excessively released. This pattern is similar to that found by Lu and Liu (1989) and Yang et al. (2004). This study also suggests that the litter of the four species could provide enough Ca, Mg and B for the different types of forest soil and accelerate the cycling of these elements in soils in southern China.

4.3 Management strategies in ecological plantations

In the late 1980s, a variety of broad-leaved tree species were planted to replace conifer plantations, but most broad-leaved species used, for example, *Falcataria moluccana*, *Acacia auriculiformis* and *Acacia mangium*, were exotic. These exotic plantations have simple stand structure and low ecological benefits. In order to enhance ecological effects, the use of native broad-leaved species for afforestation was given much attention in the late 1990s. Native species not only improve microhabitats and soil nutrients but also facilitate soil microbial activity and function, which could accelerate litter decomposition and enhance nutrient cycling in forests. In species selection, native species with high potential nutrients (especially N) are much preferred, but information on native species was limited. Therefore, studies on the biological and ecological characteristics of various potential native species are therefore urgently required for the construction and development of ecological plantations in southern China.

5 Conclusions

Litter decomposition rates of the four species were more rapid in mixed broad-leaved forest than in pine monostand, indicating that the former was better in terms of litter decomposition and nutrient cycling. Litter decomposition rates and the decomposition coefficient of the four species were in the descending order of *Cinnamomum camphora* > *Mytilaria laosensis* > *Michelia macclurei* > *Castanopsis fissa*. Litter of *Mytilaria laosensis* and *Cinnamomum camphora* had higher contents of N, Ca and Mg than *Michelia macclurei* and *Castanopsis fissa*, attributable to the higher decomposition rate in the former two species in both mixed and pine plantations. N was totally released for the four species in pine plantation, but mixed broad-leaved forest had no net N release. K was released and then accumulated for the four species and net release was only found in mixed forest. P had no clear release pattern in both plantations for the four species. Ca, Mg and B slightly accumulated initially and were then excessively released. They all had net release in both plantations. The use of native species with potentially higher leaf nutrients for afforestation in southern China is strongly recommended.

Acknowledgements The project was financially supported by the Forestry Bureau of Guangdong Province (No. 4400-F98017) and Kadoorie Farm & Botanic Garden of Hong Kong, China (No. 4400-G00003).

References

Aber J D, Melillo J M (1980). Litter decomposition: measuring relative contributions of organic matter and nitrogen to forest soils. Can J Bot, 58: 416–421

Adams M B, Angradi T R (1996). Decomposition and nutrient dynamics of hardwood leaf litter in the Fernow whole-watershed acidification experiment. For Ecol Manag, 83: 61–69

Alhamd L, Arakaki S, Hagihara A (2004). Decomposition of leaf litter of four tree species in a subtropical evergreen broad-leaved forest, Okinawa Island, Japan. For Ecol Manag, 202(1): 1–11

Angelis P D, Kesari S C, Giuseppe E S M (2000). Litter quality and decomposition in a CO_2-enriched Mediterranean forest ecosystem. Plant and Soil, 224: 31–41

Berg B, Berg M P, Bottner P, Box E, Breymeyer A, Calvo De R, Couteaux M, Escudero A, Gallardo A, Kratz W, Madeira M, Malkonen E, Mcclaugherty C, Meentemeyer V, Munoz F, Piussi P, Remacle J, Virzo de santo A (1993). Litter mass loss rates in pine forest of Europe and Eastern United States: some relationships with climate and litter quality. Biogeochemistry, 20: 127–153

Chapin F S, Matson P A, Mooney H A (2002). Principles of Terrestrial Ecosystem Ecology. New York: Springer-Verlag

Department of National Forestry Criteria of PRC (1999). Forest Soil Analysis Methods. Beijing: China Criteria Press (in Chinese)

Enriquez S, Duarte C M, Jensen K (1993). Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C: N: P content. Oecologia, 94: 457–471

Finzi A C, Schlesinger W H (2002). Species control variation in litter decomposition in a pine forest exposed to elevated CO_2. Global Change Biol, 8: 1217–1229

Gallardo A, Merino J (1993). Leaf decomposition in two Mediterranean ecosystems of southwest Spain: influence of substrate quality. Ecology, 74(1): 152–161

Gartner T B, Cardon Z G (2004). Decomposition dynamics in mixed species leaf litter. Oikos, 104: 230–246

Guo L B, Sims R E H (1999). Litter production and nutrient return in New Zealand eucalypt short rotation forests: implications for land management. Agr Ecosyst Environ, 73: 93–100

Gustafson F G (1943). Decomposition of the leaves of some forest trees under field conditions. Plant Physiol, 18: 704–707

Hu S, Chen Z, Chen Q, Miao Y (1987). Studies on the decomposition rates of leaf litter of several trees. Acta Phytoecol et Geobot Sin, 11 (2): 124–131 (in Chinese)

Jia L, Fang L, Hu Y (1998). Decomposition of leaf litter in pure and mixed stands of poplar and black locust. Chin J Appl Ecol, 9(5): 463–467 (in Chinese)

Laskowski R, Niklinska M, Maryanski M (1995). The dynamics of chemical elements in forest litter. Ecology, 76: 1393–1406

Li S, Chen Y (2004). Decomposition and nutrient return of the leaf litter under the pure and mixed plantation of *Juglans mandshrica* and *Larix gmelinii*. J Nanjing For Univ (Nat Sci Ed), 28(5): 59–62 (in Chinese)

Liao L, Ma Y, Wang S, Gao H, Yu X (2000). Decomposition of leaf litter of Chinese fir in mixture with major associated broad-leaved plantation species. Acta Phytoecol Sin, 24(1): 27–33 (in Chinese)

Liu W, Liu L, Jing G, He A (2000). Decomposition of leaf litter in *Pinus yunnanensis* forest and evergreen broad-leaved forest in central Yuannan. Acta Bot Yunnanica, 22(3): 298–306 (in Chinese)

Lu J, Liu Q (1989). Research in decomposition process of the fallen leaves in the tropical forests at Jianfengling, Hainan Island. For Res, 2(1): 25–33 (in Chinese)

Mfilinge P L, Atta N, Tsuchiya M (2002). Nutrient dynamics and leaf litter decomposition in a subtropical mangrove forest at Oura Bay, Okinawa, Japan. Trees, 16: 172–180

Office of Soil Survey, Guangdong Province (1993). Soil of Guangdong Province. Beijing: Science Press, 490–506 (in Chinese)

Olson J S (1963). Energy storage and the balance of producers and decomposers in ecological systems. Ecology, 44: 322–331

Osono T, Takeda H (2004). Potassium, calcium and magnesium dynamics during litter decomposition in a cool temperate forest. J For Res, 9: 23–31

Otsuki K, Yamanaka N, Du S, Yamamoto F, Xue Z, Wang S, Hou Q (2005). Seasonal changes of forest ecosystem in an artificial forest of *Robinia pseudoacacia* in the Loess Plateau in China. J Agr Meteorol, 60: 613–616

Pandey R R, Sharma G, Tripathi S K, Singh A K (2007). Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in northeastern India. For Ecol Manag, 240: 96–104

Wang Q K, Wang S L, Huang Y (2007). Comparisons of litterfall, litter decomposition and nutrient return in a monoculture *Cunninghamia lanceolata* and a mixed stand in southern China. For Ecol Manag, 255: 1210–1218

Weng H, LiZ, Tu M (1993). The production and nutrient contents of litter in forests of Dinghushan Mountain. Acta Phytoecol et Geobot Sin, 17 (4): 299–304 (in Chinese)

Xue L, Lai R, Chen H, Tan S, Liu L, Ke B (2002). Soil nutrients, microorganisms and enzyme activities of model afforestation land of ecological scenic forests in Baoan, Shenzhen. For Res, 15(2): 242–246 (in Chinese)

Yang Y, Guo J, Chen Y, Chen G, Zheng Y (2004). Comparatively study on litter decomposition and nutrient dynamics between plantations of *Fokienia hodginsii* and *Cunninghamia lanceolata*. Sci Silv Sin, 140 (3): 19–25 (in Chinese)

Zeng S, Su Z, Gu Y, Xie Z, Liu Y (2003). Litterfalls of major forest stands at Baiyunshan scenic spot of Guangzhou. Chin J Appl Ecol, 24 (1): 16–19 (in Chinese)

Zhang H, Zhuang X, Huang Y, Li H, Lin Y, Luo T (2003). The early growth of 11 native trees on banded cleaning-up sites. Guangxi For Sci, 32(2): 77–80 (in Chinese)

Zhou C, Yi W (2003). Decomposition of leaf litters of different tree species. J Hubei Inst Natl (Nat Sci), 21(1): 71–75 (in Chinese)

Zhuang X, Huang J, Zeng R (2001). Preliminary study on the sapling growth of 10 local broad-leaved tree species in South China. Guangdong For Sci Technol, 17(3): 11–15 (in Chinese)