植 物 学 报
Acta Botanica Sinica 2003, **45** (4): 399 - 407 http://www.chineseplantscience.com

Comparison of Major Nutrient Release Patterns of *Quercus liaotungensis* Leaf Litter Decomposition in Different Climatic Zones

WANG Li-Xin, WANG Jin, HUANG Jian-Hui*

(*Laboratory of Quantitative Vegetation Ecology*, *Institute of Botany*, *The Chinese Academy of Sciences*, Beijing 100093, China)

Abstract: Leaf litter decomposition of liaotong oak (*Quercus liaotungensis* Koize) under temperate, subtropical and tropical forests was examined using a litter bag technique. Decomposition rates and release dynamics of nutrients Ca, Cu, Fe, K, Mg, Mn and P were observed separately at all three sites for 1 to 2 a periods. The leaf litter mass loss of liaotong oak was simulated with Olson's exponential model. Significant differences of leaf litter mass loss were found in forests of all three climate zones. Litter decomposition was accelerated with the increase of both annual mean precipitation and temperature. Our results agreed with other studies demonstrating that litter decomposition processes were greatly affected not only by soil organisms (including soil fauna and microorganisms), but also by chemical factors. These chemical factors were important for controlling the release of nutrients, especially elements of Fe and Mn. We also found that Fe and Mn content increased in semi-decayed leaf litter as litter mass decreased. This result was presumably due to chelating process which accumulated soil Fe and Mn ions into the decomposing litter. In conclusion, our study allowed us to determine the classification of the characteristics of different nutrient release patterns.

Key words: liaotong oak (*Quercus liaotungensis*); leaf litter; decomposition; temperate; subtropics; tropics

Litter decomposition is a critical process in ecosystem biogeochemistry cycles, during which nutrients get mineralized. There are two parallel processes: decomposition of organic material and formation of humus. After these two processes nutrients enter the material cycle. Facelli and Pickett (1991) pointed out that litter is not only a pool for nutrients transfer, but also an important factor affecting community organization and dynamics.

Litter decomposition is a complex process, including series of physical and biochemical processes. During these processes, soil microorganisms play significant roles. Litter decomposition rates and nutrient mineralization are basically accomplished by the activities of soil microorganisms. Therefore, if environmental conditions in an ecosystem are favorable, the decomposition rate will be high (Huang *et al*, 1998). Temperature and precipitation are among the most important environmental variables, which may influence litter decomposition.

With limited research methods and relatively expensive experimental cost, the study of litter decomposition has not reached such level as nutrient release dynamics until recently (Lousier and Parkinson, 1978; Blair, 1988; Laskowski *et al*, 1995; Dighton, 1995). Relevant research in China is even less (Zheng *et al*, 1995; Wang and Huang, 2001), with no findings pertaining to specific nutrient release dynamics. In addition, given varying climatic conditions and different element functions on plant species, still no common nutrient release model at regional or global scale has been developed.

Carbon dioxide release during litter decomposition is regarded as the most important part of soil processes, releasing CO_2 into the atmosphere. Research on global climate change shows that there will be a continuous rise in temperature and precipitation in the future, affecting leaf litter decomposition rates. Our objectives for this study are: (1) to compare the decomposition rates of leaf litter of liaotong oak in three areas with significantly different temperature and precipitation (Donglingshan Mountain in temperate zone, Shennongjia in subtropical zone and Xishuangbanna in tropical area); (2) to address the effect of possible climate change on litter decomposition rates; and (3) to determine general nutrient release patterns during litter decomposition and their affecting factors.

1 Materials and Methods

1.1 Description of study sites

Experiments were separately conducted in Donglingshan Mountain (temperate site), Shennongjia (subtropical site) and Xishuangbanna (tropical site). The Donglingshan Mountain site was located in an experimental area of Beijing Forest Ecosystem Research Station of the Chinese Academy of Sciences at Mentougou, West Beijing (40°01′ N, 115°28′ E). The elevation was 1 200 m.a.s.l. This region experiences a semi-arid temperate climate characterized by warm, humid summers and cold, dry winters, with annual precipitation of 600 mm, and annual average temperature of 2 - 8 ℃. Decomposition samples were placed in a deciduous forest dominated by *Quercus liaotungensis* Koize, other important tree species

---

Received: 2002-02-04 Accepted: 2002-12-10
Supported by the State Key Basic Research and Development Plan of China (G20000046802-04).

* Author for correspondence.

include Dahurian birch (*Betula dahurica* Pall.), Mono Maple (*Acer mono* Maxim.), and Manchurian Linden (*Tilia mandshurica* Rupr et Maxim.). Manchurian hazelnut (*Corylus mandshurica* Maxim.), twinflower abelia (*Abelia biflora* Turez.), and largeflower deutzia (*Deutzia grandiflora* Bunge.) are dominant shrub species, while common small reed (*Calamagrostis arundinacea* (Linn.) Roth.) and rigescent sedge (*Carex rigescens* (Franch.) V. Krecz.) dominate herbaceous layer.

The Shennongjia site was located in the Northwestern Hubei Province (110°29′ N, 30°19′ E). The elevation was 1 700 m.a.s.l. This area belongs to the north subtropical zone. The average annual temperature is 4.6 ℃ (1998, 1999) (The Meteorology station is located at 1 290 m above sea level), and annual precipitation is 1 303.6 mm. Decomposition samples were placed under an Engler beech (*Fagus engleriana*) forest. The major woody species include Engler beech, several species of maple (*Acer* spp.), Hemsley Cornel dogwood (*Cornus hemsleyi* Shneid. et Wanger.), several species of oak (*Cyclobalanopsis* spp. Oerst.) and Tanoak (*Lithocarpus* spp. Bl.).

Xishuangbanna site was located in southern Yunnan Province (21°50′ N, 101°12′ E), which borders Laos and Myanmar, with a typical monsoon tropical climate characterized by relatively cool rainy season from May to October, and warm dry season from November to April. The elevation of the site was at 730 m.a.s.l. The annual active accumulative temperature could amount to 7 500 ℃. Liaotong oak leaf litter decomposition bags were placed on the forest floor of a seasonal rain forest. The dominant species is *Pometia tomentosa* (Bl.) Teysm. et Binn, and the sub-dominant species include *Barringtonia macrostachya* (Jack) Kurz, *Chisocheton siamensis* Craib, *Gironniera subaequalis* Planch, *Mezzettiopsis creaghii* Ridl, *Ardisia tenera* Mez and *Dichapetalum gelonioides* (Roxb.) Engl. Average annual temperature there is 21.8 ℃, and the annual precipitation is 1 550 mm.

1.2 Study methods

A mesh bag method was used in this experiment. The mesh bag approach is simple and easy to carry out, thus common in studies of forest floor decomposition. However, the mesh size may affect study result (Wang and Huang, 2001). Lousier and Parkinson (1976) pointed out that the extent of compactness would result in different humidity which could affect decomposition rates. One mm nylon meshed bags were used based on leaf sample size, keeping sample from being highly compacted. Freshly fallen liaotong oak leaf litter were collected with net traps under the oak forests during the periods of maximum litterfall (late September to early November). Five grams of air-dried litter was placed in each 1 mm-mesh bag. The litter bags were distributed in Donglingshan Mountain, Shennongjia and Xishuangbanna sites on October 25th, 1997; March 31st, 1998 and December 27th, 1997 respectively. All the mesh bags were randomly distributed to five points on the forest floor and tied with iron cords, fixed around the base of tree stems. The first sampling occurred May 6th, 1998, May 10th, 1998 and January 24th, 1998 respectively at the three sites. Decomposed litter was collected at intervals of half a month or two months depending on the site and season of the year. After sampling, leaf litter were washed free of soil and then oven-dried at 80 ℃ until reaching a constant weight. After weighing, all the samples were grounded for chemical analysis.

1.3 Analysis for major elements

Total nitrogen content was measured using the Kjeldahl method after digesting with H_2SO_4. Total organic matter content was measured with H_2SO_4-$K_2Cr_2O_5$ method, and other elements were measured using ICP after digested with HNO_3-$HClO_4$.

2 Results and Analysis

Donglingshan Mountain, Shennongjia and Xishuangbanna belong to temperate, subtropical and tropical climate zones. Comparison of the decomposition in these three different climate zones allows for the study of decomposition under different temperature and precipitation. This comparison also allows for the prediction of the changes of litter decomposition under given global warming conditions. The decomposition process of oak leaf litter can be simulated by Olson exponential equation (1963) in all of the three sites as:

Donglingshan Mountain

$$y = 102.78e^{-0.215\,1x} \quad r = 0.828\,1 \quad n = 11\ (P < 0.01)$$

Shennongjia

$$y = 96.376e^{-0.430\,8x} \quad r = 0.935\,1 \quad n = 13\ (P < 0.01)$$

Xishuangbanna

$$y = 115.19e^{-1.116\,9x} \quad r = 0.874\,9 \quad n = 16\ (P < 0.01)$$

Ninty-five percent of the leaf litter will decompose completely within 13.95 a in Donglingshan Mountain, 6.96 a in Shennongjia and 2.86 a in Xishuangbanna respectively (Table 1, Fig.1).

Litter decomposition rates are strongly affected by climate, especially temperature and precipitation. With the increase of precipitation and annual average temperature, litter decomposition rate increases accordingly.

Table 1 Comparison of the four coefficients describing litter decomposition rates in three temperate, subtropical and tropical regions

Sites	Decomposition rate K (/a)	r	1/K (a)*	3/K (a)**
Donglingshan Mountain	0.215	0.828 1	4.65	13.95
Shengnongjia district	0.431	0.935 1	2.32	6.96
Xishuangbanna district	1.117	0.874 9	0.89	2.69

1/K* and 3/K** are both the decomposition rates, namely, the time needed for 63.2% and 95% of the litter decomposed, respectively.

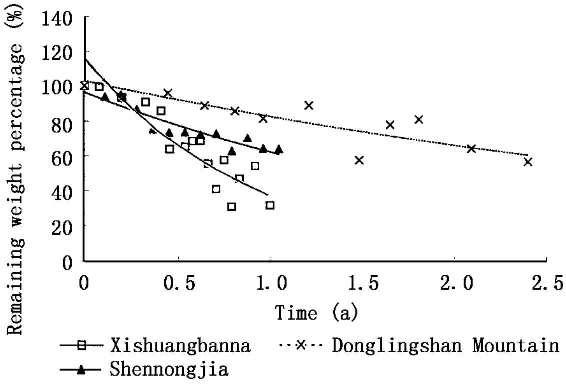

Fig.1. Exponential simulation of *Quercus liaotungensis* mass loss during decomposition in Xishuangbanna, Shennongjia and Donglingshan Moutain.

These results were similar to Zhong and Du (1997) on the study of relationship of litter decomposition of red clover (*Trifolium pretense* L.) and common orchard grass (*Dactylis glomerata* L.) with temperature and precipitation. Laskowski *et al* (1995) found that element concentration and absolute content are both important ecologically. Changes in concentrations directly affect nutrient availability and/or some ions' toxicity to plant and soil microorganisms. While changes of absolute content are very important for predicting ecosystem change, we analyzed both concentration and remaining percentage (showing the absolute content) (Figs. 2, 3).

2.1 Potassium

Potassium (K) is not a structural component of plant tissue, and K^+ is easily removed, so dead tissue would not be expected to hold K^+ against leaching and decomposition (Gosz *et al*, 1973). In our experiment, remaining percentages of K decreased rapidly in all three sites. In Shennongjia and Xishuangbanna sites, K^+ release was correlated with litter mass loss significantly ($r = 0.745$, $P < 0.01$; $r = 0.767$, $P < 0.01$), showing that precipitation strongly affected litter decomposition in these two sites, not only for K^+, which is easy to be leached, but also for leaf litter. From the beginning of the experiment, K^+ quickly went into release phase in Shennongjia site, this release pattern was related to the precipitation at Shennongjia site (see analysis of Mg or Cu for the detail precipitation). In Xishuangbanna site, K remaining percentage increased firstly, then decreased, and gradually fell into the leaching phase. The somewhat late occurrence of the leaching phase can also be explained by climatic condition especially precipitation. The experiment started in Xishuangbanna in late January with very little precipitation (1 mm), far less than the peak precipitation period from May to August (see analysis of Mg or Cu for detailed precipitation). In Donglingshan Mountain, K release pattern was different from both Shennongjia and Xishuangbanna sites, that is, it first decreased until reaching the lowest point, then increased a little, and decreased again. The quick decrease of K concentration and remaining percentage in the beginning shows the significant effects of leaching during decomposition (Bockheim and Leide, 1986; Enright and Ogolen, 1987). Alexander (1977) also found that K release did not correlate with microorganisms' activities but from leaching.

Laskowski *et al* (1995) proposed a general pattern of K^+ release based on one experimental and 138 field studies. Potassium release processes can be divided into two stages, rapid concentration change and later stabilization with K^+ concentration being close to that in humus. Based on initial K^+ content, Laskowski *et al* (1995) classified K^+ release into three patterns. In our experiment, K^+ initial content in oak leaf litter was 3.16 mg/g, which was in the range of 0.6 – 4.0 mg/g. According to Laskowski, K^+ release should decrease first, then increase, but in fact, only K^+ release in Donglingshan Mountain site in our experiment exhibited this pattern, while in Shennongjia and Xishuangbanna sites, K^+ was released from the very beginning, which means that the so-called general pattern for K^+ release is, only applicable to litter decomposition in some specific climate zones.

Laskowski *et al* (1995) also pointed out that the equilibrium concentration of K^+ release was 0.8 – 1.2 mg/g. In our experiment, the final K concentrations in Donglingshan Mountain, Shennongjia and Xishuangbanna were 1.5, 1.0 and 0.86 mg/g, respectively. Based on the decomposition trend and final concentration, we conclude that in Shennongjia, K^+ release was halted while in Xishuangbanna K^+ release may continue although the final concentration was within the Laskowski's equilibrium range. In Donglingshan Mountain, K^+ was found to continue release. At the end of our experiment, the remaining percentages in Donglingshan Mountain, Shennongjia and Xishuangbanna were 47.31%, 31.60% and 27.31%, respectively.

2.2 Calcium

Calcium (Ca) is a macronutrient that is required by most higher plants and a critical structural component. Most of the Ca in plants is stored in the leaves, so release of Ca from leaf litter is critical for the entire Ca cycle in ecosystem. In Donglingshan Mountain and Shennongjia sites, the remaining percentage and concentration of Ca rose from the very beginning. Calcium absolute content tended to increase throughout the entire study, although concentrations were relatively stable with no great changes. We found leaching did not occur throughout the study. Calcium release did not correlate with mass loss, which was similar to the study of Lousier and Parkinson (1978). They suggested that the release of Ca was mainly caused by decomposition, not leaching. Until the end of the experiment, there was no evidence of Ca release in Shennongjia site, while Ca started to release from 0.96 a after the onset of the experiment at Donglingshan Mountain. In Xishuangbanna site, Ca began to release from the beginning of the experiment, and was significantly correlated with leaf mass loss ($r = 0.669$, $P < 0.05$). There was little change in Ca concentration in Xishuangbanna

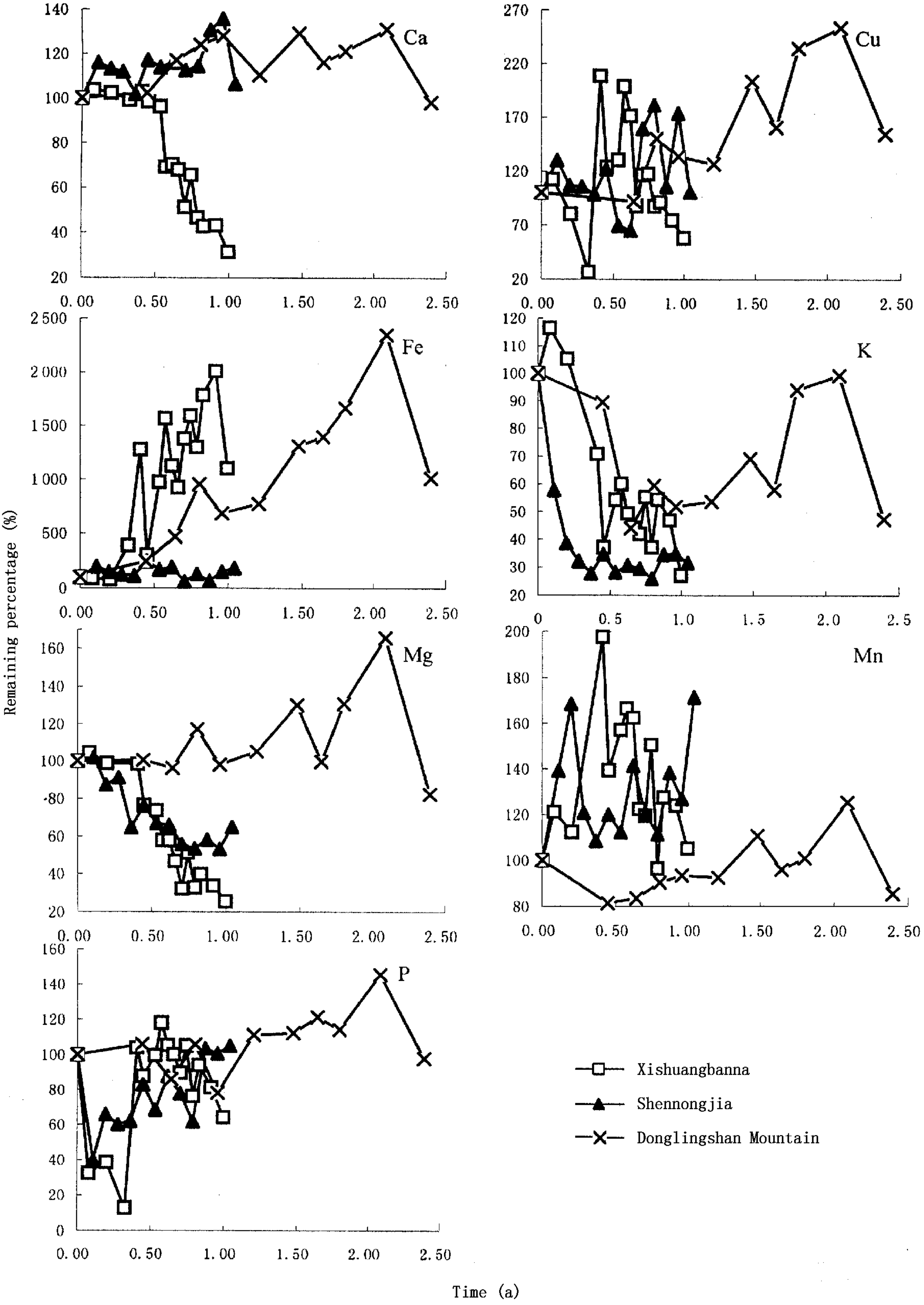

Fig.2. Changes of nutrient remaining rate with time in *Quercus liaotungensis* leaf litter which decomposed in Xishuangbanna, Shennongjia and Donglingshan Mountain.

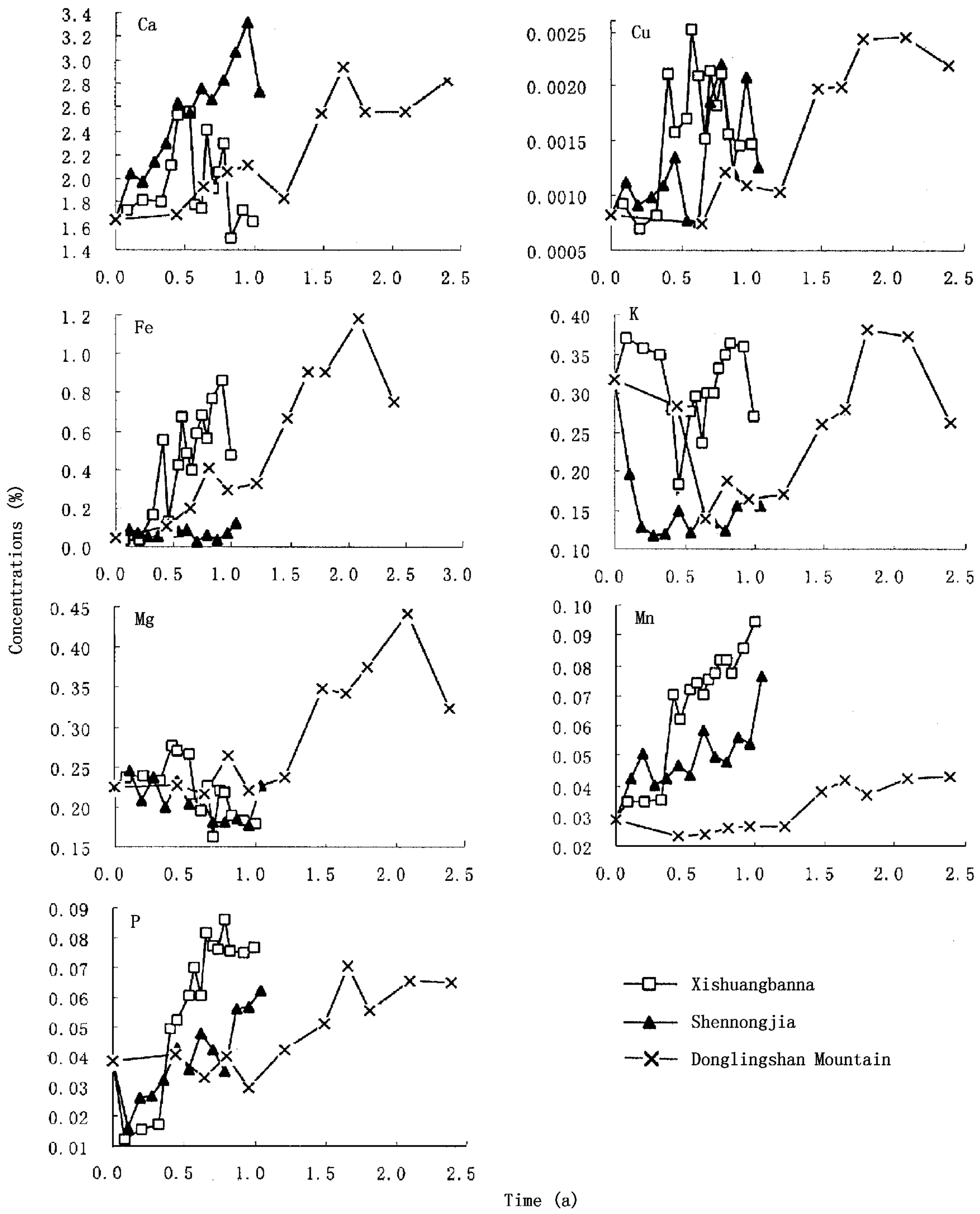

Fig.3. Changes of nutrient concentrations with time in *Quercus liaotungensis* leaf litter which decomposed in Xishuangbanna, Shennongjia and Donglingshan Mountain.

site, which is different from the increasing Ca concentrations at Shennongjia and Donglingshan Mountain sites. This indicated that Ca is a structural component of leaves and its release happens during the process of decomposition. Such results were similar to the study of dogwood litter decomposition (Thomas, 1969). Ca did not release soon after the beginning of field incubation instead, it accumulated in Donglingshan Mountain and Shennongjia sites, partly because of the high C/Ca ratio of the liaotong oak leaf litter. For an element that is decomposed mostly by microorganisms, the initial ratio between carbon and that element concentration is usually used as a critical value for nutrient release (Lousier and Parkinson, 1978). There was proof (unpublished data) that the critical value for Ca release in the temperate zone was between 11 and 14, while in this experiment the C/Ca value was 25.66. We found that precipitation was not responsible for fast release of Ca in Xishuangbanna site, because there was very little precipitation (approximately 1 mm) when the experiment began. Presumably the high activity and large quantity of microorganisms or fewer requirements for Ca, or an interaction of these two factors contributed to the results in Xishuangbanna. At the end of the experiment, the remaining percentages in Donglingshan Mountain, Shennongjia and Xishuangbanna sites were 98.0%, 106.4% and 31.5% respectively, the Ca loss rate in Xishuangbanna district was much larger than in the other two sites.

2.3 Magnesium

Magnesium (Mg) began release relatively after stabilization in both Shennongjia and Xishuangbanna sites. The fast release period occurred during 0.54 – 0.79 and 0.58 – 0.87 a from the beginning of the experiment. This corresponded to the rainy season from May to August in both areas. The precipitation in the two regions was 181.8, 208.0, 428.3, 436.5 mm/month for the Shennongjia site and 108, 247, 508, 379 mm/month for Xishuangbanna site. Magnesium release in both sites was significantly correlated with leaf litter mass loss ($r = 0.928$, $P < 0.01$ and $r = 0.8$, $P < 0.01$). From these results, we conclude that, Mg release was affected by both physical leaching and microbial activity in Shennongjia and Xishuangbanna sites. The fact that Mg concentration in the litter did not change much in the two sites further showed that the reduction of Mg paralleled with decomposition of organic matter. Blair (1988) found that Mg release in early periods, leaching contributed greatly, while in the latter periods, microbial effect was more significant. In Donglingshan Mountain, Mg was relatively stable before reaching a maximum remaining percentage (165.70%) at 2.09 a. It was after 2.09 a in which Ca was released. This relatively stable process proved that Mg release did not correlate with litter mass loss. This release pattern was similar to two other tree species, e.g. two lindens (*Tilia mongolica*, *T. mandshurica*, etc.) from the same region (unpublished data). So, lack of correlation was not caused by litter quality, but was determined by climate or microbial activity or interaction of them. Gosz *et al* (1973) suggested, when Mg began to release, the minimum C/Mg ratio in concentration was 900∶1 to 1 350∶1, and the minimum C/P ratio in concentration was 0.5∶1 to 1∶1. In our experiment, the C/Mg ratio was 188.70, far less than 900∶1, presumably that was the reason why the remaining percentage of Mg showed an increasing trend from the beginning in all three sites. Some ecologists considered that Mg release was mostly affected by microbial effects during the process of organic matter decomposition, which was characterized by linear relationship between Mg release and litter mass loss (Staaf and Berg, 1982; Rapp and Leonardi, 1988). Other findings suggested that Mg release was mainly affected by physical leaching (Dziadowiec, 1987). Our findings showed that Mg release was affected by both microbial and physical leaching. However, the two factors interchangeably affected each other. When microbial effects increased, physical leaching decreased. At the end of the experiment, the remaining percentages in Donglingshan Mountain, Shennongjia and Xishuangbanna sites were 82.40%, 65.10% and 25.52%, respectively.

2.4 Iron

The concentration and remaining percentage of iron (Fe) changed greatly in all three sites especially in Xishuangbanna where large levels of enrichment occurred. At the end of the experiment, the remaining percentages in Donglingshan Mountain, Shennongjia and Xishuangbanna sites were 1 106.45%, 184.9% and 1 014.35% respectively. Rustad (1994) found that Fe remaining percentages were 340% and 870% in the study of white pine and red pine litter decomposition. In Donglingshan Mountain and Xishuangbanna sites, Fe release was negatively correlated with litter mass loss significantly ($r = -0.813$, $P < 0.01$ and $r = -0.752$, $P < 0.01$). Gosz *et al* (1973) found a similar phenomenon, given high soil Fe concentrations and high soil acidity. This allowed for Fe^{2+} and other dissolved ions in top portions of the soil layer to become incorporated into leaf litter. Leaf shedding could last for a long time in Xishuangbanna site, based on concept of litter decomposition of Gosz *et al*, fresh leaf litter would contribute Fe to the forest floor continuously. While this could explain part of the phenomenon, it did not explain why Fe release was negatively correlated with litter mass loss. We suggested that Fe release followed these processes in Donglingshan Mountain and Xishuangbanna sites: firstly, litter might be decomposed by microorganism, producing organic by-products (e.g. humic and fulvic acids). Stevenson (1982) found that humic and fulvic acids had high ability of chelating. Secondly, the by-products might chelate Fe cations in the soil while processing leaf litter decomposition. Therefore Fe absolute content in leaf litter increased with the accumulation of by-products. Since the most important characteristic in this decomposition pattern was the production of chemicals such as humic and fulvic acids by microorganism, it was termed "Chemical effect dominance" decomposition pattern. Under this pattern, the content change would not directly depend on microbial activity. The decomposition process had a significant feature, that is, the element release was negatively correlated with litter mass loss. Laskowski *et al* (1995) proposed a similar idea stating that Fe, Zn, Pb and Cd all belonged to this pattern, but did not describe the features of this decomposition pattern. In Shennongjia site, Fe release did not correlate negatively with litter mass loss. Iron release should belong to other patterns in this area. The high extent of increase of Fe concentration and remaining percentage was caused by microbial enrichment. Changes of Fe concentration and remaining percentage were similar in all of the three sites in our study.

2.5 Phosphorus

Phosphorus (P) is also an important element next to N in plant nutrition. But compared with other elements, the content of available P in soil is very low, so the cycle of P in soils mainly depends on microbial activities (Gosz *et al*, 1973). In our experiment, P concentration in the three sites increased over time, but the changes of P remaining percentage did not keep step with each other. The finding was different from what Gosz *et al* (1973) observed. They found that both P concentration and remaining percentage increased during the whole experiment period. While in our experiment, P loss in Donglingshan Mountain site was different from that in Xishuangbanna and Shennongjia sites. In Donglingshan Mountain, P remaining percentages reached a maximum (145.42%) after a relatively stable period (~1.8 a), then decreased dramatically. At the end of the experiment, the P remaining percentage almost approached its initial value (97.81%). During the whole experimental period, P remaining percentages kept relatively stable, and no clear leaching or release period was found. At the Shennongjia site, P remaining percentages decreased greatly and then went into an accumulation period. Showing little fluctuation, the increasing trend was fairly clear. At the end of the experiment, P remaining percentages reached the initial value (105.1%). In Shennongjia site, the rapid decrease of absolute P content in the beginning was possibly due to high initial P content in oak leaf litter. But physical leaching was not the main effect influencing P release since P was in the state of accumulation in the following rainy season from May to August. In Xishuangbanna site, the absolute P content also decreased dramatically at the beginning, then increasing rapidly to a maximum remaining percentage (118.08%) and began to release thereafter. At the end of the experiment, P remaining percentage was 64.16%. From January to March, it was not the rainy season at the Xishuangbanna site with almost no precipitation, so the rapid decrease of P content definitely did not caused by physical leaching. P is a non-metal element, thus would not be chelated and decomposed following the "Chemical effect dominance" pattern. Phosphorus loss in all three sites was caused by a biological effect. The difference among all three sites was a product of different regional climates. The temperature and humidity in the latter two sites may be more favorable for microorganism growth and activity. Of course, there were other reasons that would contribute to the increasing of P content. For example, Gosz *et al* (1973) mentioned that P content in rainwater was low, so the increase of absolute P content resulted from the uptake of P from flower, pollen, fresh litter and soil organic layer. In our experiment, P loss did not correlate with litter mass loss during the whole decomposition period in all the three sites. These results differed from the findings of both Attiwill (1968) and of Lousier and Parkinson (1978). Such difference shows the complexity of element loss patterns: even for the same element, the loss pattern may not be the same under different climate condition, from different plants or from different organs in the same plant.

2.6 Copper

In Donglingshan Mountain site, the Copper (Cu) and Ca followed similar release patterns, i.e., accumulating from the beginning of the experiment resulting in the continuous increase of both the concentration and remaining percentage. At the end of our experiment, Cu remaining percentage was still higher than 100%. In Shennongjia site, Cu remaining percentage decreased gradually at first and reached the lowest point (65.21%) in November of 1998, then increased gradually and reached the highest point (181.4%), and then decreased again. Although there were some fluctuations, Cu concentration generally increased. In Shengnongjia site, the experiment began during the rainy season from May through August, the precipitation was 181.8, 208.0, 428.5 and 436.5 mm, respectively. So the rapid decrease of Cu remaining percentage was most probably caused by leaching. The following increase and then decrease was caused by microbial accumulation and release. In Xishuangbanna site, Cu remaining percentage decreased at first until reaching the lowest point (26.67%) on April 24th, and then began to accumulate until reaching the highest point (208.61%) on May 24th, 1998 and then went into the releasing period. The change of Cu concentration was similar to that of remaining percentage, that is, it decreased at first, then increased, reaching the highest point and then decreasing again. The period of Cu release responded to the rainy season in Xishuangbanna from May to August, the precipitations were 108, 247, 508 and 379 mm, respectively, which indicated that leaching may have been responsible for Cu release. Gosz *et al* (1973) believed that leaching should be the most important way for Cu loss, which agreed well with our study result. If an element is a structural component, its release will correlate with litter mass loss. While in our experiment, Cu loss did not correlated with litter mass loss in all three sites, thus we conclude that Cu was not a structural component in the oak leaf litter. At the end of the experiment, Cu remaining percentages in Donglingshan Mountain, Shennongjia and Xishuangbanna sites were 154.140%, 100.5% and 58.09%, respectively.

2.7 Manganese

In Donglingshan Mountain site, Manganese (Mn) first was stable for a period of 1.21 a from the beginning of the experiment, then increased dramatically and reached a maximum remaining percentage (125.48%), followed by remarkable decrease. At the end of the experiment, the remaining percentage reached the initial level (~80%). The release of Mn negatively correlated with litter mass loss ($r = -0.611$, $P < 0.05$), meaning that Mn release followed the "Chemical effect dominance" pattern. In Shennongjia and Xishuangbanna sites, Mn's release did not correlate with litter mass loss ($r = -0.043$ and $r = -0.093$), indicating that the release patterns in the three sites were different. Mn's release depended on microbial activity in Shennongjia and Xishuangbanna sites since there was no physical leaching. In these two sites, Mn's concentration increased all the time while remaining percentages decreased after reaching maximum. The difference in the change of concentration and remaining percentage proved that Mn was easier to lose than organic matter. The C/Mn ratios in Shennongjia and Xishuangbanna sites were different (891.15 and 484.37, respectively) at the time when Mn began to release. This difference most probably resulted from the different microbial requirements for one element under different climate conditions. At the end of our experiment, the remaining percentage in Donglingshan Mountain, Shennongjia and

Xishuangbanna sites were 85.58%, 171.7% and 105.37%, respectively.

3 Discussion

Based on the results of previous research and our own experiment, we found that there are many factors which may affect element release during litter decomposition processes. Among them, environmental factors as well as litter quality are of major importance. Biological factors, which are carried out by microbial activity, are critically important. However, with respect to some elements such as K and Mg, leaching is also significant. Sometimes the effects of leaching may even surpass biological ones. In addition, for Fe and Mn, a new decomposition pattern was found, that is, "Chemical effect dominance", in which the release of the element is affected by microorganism, with its own feature different from that of "Biological effect dominance". To compare and contrast these patterns we summarized the features as follows:

Biological effect dominance The releases of most elements, such as Ca, Cu and Mg, follow this pattern. The most significant feature of this pattern is the significant correlation between element release and litter mass loss. In general, there is a critical value for element releases, i.e., the C/element ratio. The element will not begin to release unless the ratio gets below the critical value (Lousier and Parkinson, 1978). Under such a pattern, if an element has higher initial content in litter, it will release directly without accumulation.

Chemical effect dominance Affecting only Fe and Mn in our experiment. These elements are released in this pattern during litter decomposition processes. The mechanism of this pattern is that some compounds are first produced during decomposition, and such compounds as humic and fulvic acids will chelate metal cations in soil, thus greatly increasing the content of metal cations in litter along with litter decomposition. The most significant feature of this pattern is the negative correlation between element release and litter mass loss.

Physical effect dominance The release of elements, which usually are not structural components of plants (such as K and Mg), and will not accumulate in litter. These elements are controlled mostly by physical leaching. The characteristic of this pattern is that elements release from the very beginning of litter decomposition and are significantly correlated with precipitation.

However, one should keep in mind that the release of an element in litter during the decomposition process is usually affected by multiple factors, the dominant effect may differ in different decomposition stages. Moreover, not only will the element in different litter be released with different patterns, but also the same element in the same litter will be released following different patterns under different climates (in our experiment, Mn is released following different patterns in Donglingshan Mountain, Xishuangbanna and Shennongjia sites).

4 Conclusion

Litter decomposition is obviously affected by climate. With increasing precipitation and mean annual temperature, the litter decomposition rates will increase. Based on Olson exponential equation (Olson, 1963), the complete decomposition of the oak leaf litter in Donglingshan Mountain site will take 13.95 a while just 2.67 a in Xishuangbanna site.

At the end of the experiment, the litter mass loss rates and element loss rates of litter were:

In Donglingshan Mountain site, K > litter mass > Mg > Mn > P > Ca > Cu > Fe

In Shennongjia site, K > litter mass > Mg > Cu > P > Ca > Mn > Fe

In Xishuangbanna site, Mg > K > Ca > litter mass > Cu > P > Mn > Fe

Compared to other results, different species and different habitats will greatly influence element movement. For example, the order of release rate during decomposition was K > Na > P > Zn > Mg > Ca > N > Mn > Cu > Fe for aspen in temperate climate (Lousie and Parkinson 1978); Na > Cl > K > Mg > S > Ca > N > P for eucalyptus under Mediterranean climate (O'Connell, 1988), and K > Mg > Ca > S > Cu > Na > Mn = N > Cd > Pb = Zn > Fe for the average decomposition rate of oak, pine and beech in south Poland (Laskowski *et al*, 1995).

As for the elements of which the release is primarily controlled by microorganisms during decomposition, there is usually a threshold for the C/element ratio that determines the release of the element (e.g. Ca release). According to our experiment, we found that these values are meaningful only in a particular climate zone. For example, Mn has different threshold values in Shennongjia and Xishuangbanna sites.

Acknowledgements: We appreciate the help of distributing and sampling litter bags by Dr. HE Jin-Sheng, Shennongjia Biodiversity Research Station, The Chinese Academy of Sciences and Mr. TANG Jian-Wei, Tropical Forest Ecosystem Station, Xishuangbanna Tropical Botanical Garden, The Chinese Academy of Sciences. We also appreciate the comments on the manuscript from Dr. MOU Pu and Mr. Bishop Blair, University of North Carolina at Greensboro, USA and the two anonymous reviewers.

References:

Alexander M. 1977. Introduction to Soil Microbiology. New York: John Wiley and Sons. 467.

Attiwill P M. 1968. The loss of elements from decomposition litter. *Ecology*, **49**:142 – 145.

Blair J M. 1988. Nutrient release from decomposing foliar litter of three tree species with special reference to calcium, magnesium and potassium dynamics. *Plant Soil*, **110**:49 – 55.

Bockheim J G, Leide L E. 1986. Litter and forest floor dynamics in Wisconsin. *Plant Soil*, **96**:393 – 406.

Dighton J. 1995. Nutrient cycling in different terrestrial ecosystems in relation to fungi. *Can J Bot*, **73**:S1349 – S1360.

Dziadowiec H. 1987. The decomposition of plant litter fall in an oak-linden-hornbeam forest and oak-pine mixed forest of the Bialowieza National Park. *Acta Soc Bot Pol*, **56**:169 – 185.

Enright N J, Ogolen J. 1987. Decomposition of litter from common woody species of kauri (*Agathis australis* Salisb.) forest in northern New Zealand. *Aust J Ecol*, **12**:109 – 124.

Facelli J M, Pickett S T A. 1991. Plant litter: its dynamics and effect on plant community structure. *Bot Rev*, **57**:1 – 32.

Gosz J R, Likens G E, Bormann F H. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook forest, New Hampshire. *Ecol Monogr*, **53**:173 – 191.

Huang J-H (黄建辉), Chen L-Z (陈灵芝), Han X-G (韩兴国). 1998. Advances in litter decomposition in forest ecosystems. Li C-S (李承森). Advances in Plant Sciences. Beijing: China Higher Education Press. 218 – 236. (in Chinese)

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

Lousier J D, Parkinson D. 1976. Litter decomposition in a cool temperate deciduous forest. *Can J Bot*, **54**:419 – 436.

Lousier J D, Parkinson D. 1978. Chemical element dynamics in decomposing leaf litter. *Can J Bot*, **56**:2795 – 2812.

O'Connell A M. 1988. Nutrient dynamics in decomposing litter in Karri (Eucalyptus Diversicolor F. Muell.) forests of southwestern Australia. *J Ecol*, **76**:1186 – 1203.

Olson J S. 1963. Energy storage and the balance of producers and decomposition in ecological systems. *Ecology*, **44**:332 – 331.

Rapp M, Leonardi S. 1988. Evolution de la litiere au sol au cours d'une annee dans un taillis de chene vert (*Quercus ilex*). *Pedobiologia*, **32**:177 – 185.

Rustad L E. 1994. Element dynamics along a decay continuum in a red spruce ecosystem in Maine, USA. *Ecology*, **75**:867 – 879.

Staaf H, Berg B. 1982. Accumulation and release of plant nutrients in decomposing Scots pine needle litter. Long-term decomposition in a Scots pine forest Ⅱ. *Can J Bot*, **60**:1561 – 1568.

Stevenson F J. 1982. Humus Chemistry: Genesis, Compositions, Reactions. New York: John Wiley and Sons.

Thomas W A. 1969. Accumulation and cycling of calcium by dogwood trees. *Ecol Monogr*, **39**:101 – 120.

Wang J (王瑾), Huang J-H (黄建辉). 2001. Comparison of major nutrient release patterns in leaf litter decomposition in a temperate forest in Donglingshan Mountain. *Acta Phytoecol Sin* (植物生态学报), **25**:375 – 380. (in Chinese with English abstract)

Zheng W-J (郑文教), Shao C (邵成), Wang L-M (王良睦), Lin P (林鹏). 1995. Dynamics of nutrient elements in litterfall of subtropical of rain forest of Hexi in Fujian. *J Trop Subtrop Bot* (热带亚热带植物学报), **3**(4):38 – 43. (in Chinese with English abstract)

Zhong H-P (钟华平), Du Z-C (杜占池). 1997. The relationship between the climatic factors and the litter decomposition of *Trifolium pratense, Dactylis glomerata* in Mountains of eastern Sichuan. *Grassland China* (中国草地), **6**: 29 – 32. (in Chinese with English abstract)

(Managing editor：HAN Ya-Qin)

辽东栎叶片凋落物在不同气候带下的分解及其主要元素释放的比较

王立新　王　瑾　黄建辉[*]

(中国科学院植物研究所植被数量生态学重点实验室，北京 100093)

摘要： 应用分解网袋法对辽东栎(*Quercus liaotungensis* Koize)叶片凋落物分别在暖温带的东灵山、亚热带的神农架、热带的西双版纳为期 1～2 年的分解和 K、Ca、Mg、Fe、P、Cu、Mn 等营养元素释放动态进行比较研究。三个气候带下辽东栎叶片凋落物质量损失基本符合 Olson 的指数模型，但降解速率有很大的差别。气候条件对凋落物的分解和营养元素的释放影响很大，降水量增多，年均温增高，凋落物分解速率相应加快。研究还发现影响营养元素释放的因素除了公认的土壤生物(土壤动物和土壤微生物)作用外，对于 Fe、Mn 等元素遵循的是'化学因素主导'模式，特征在于由于化学螯合作用，其释放过程和凋落物本身失重呈显著负相关。另外，对不同因素占主导的各种分解模式进行了归纳总结。

关键词： 辽东栎；叶片凋落物；分解；暖温带；亚热带；热带

中图分类号：Q948.1　　**文献标识码：**A　　**文章编号：**0577-7496(2003)04-0399-09

收稿日期：2002-02-04　**接收日期：**2002-12-10

基金项目：国家重点基础研究发展规划项目(G2000046802-04)。

[*] 通讯作者。

(责任编辑：韩亚琴)