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## Indirect effects of precipitation variation on the decomposition process of Mongolian oak (*Quercus mongolica*) leaf litter

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**Abstract** The effect of precipitation variation on the chemistry of Mongolian oak (*Quercus mongolica*) leaf litters was examined by analyzing litters of Mongolia oak saplings under four precipitation gradients. The decomposing process of these leaf litters in the Mongolian oak dominated forest was assessed using litter bag method. Compared with the litters of the Mongolian oak saplings from the natural precipitation site (A), litters produced by Mongolian oak from the driest precipitation gradient ( $A_{450}$ ) had significantly higher concentrations of nitrogen (N), phosphorus (P) and potassium (K) while lower acid-insoluble fraction (AIF) concentration. The decomposition study showed that  $A_{450}$  exhibited significantly higher decomposition rate, mineralization rates of N, P and K as well as much shorter N and P net immobilization periods. On the contrary, litters produced by seedlings from wettest gradient ( $A_{850}$ ) showed a totally opposite pattern. Litters from saplings that received comparable precipitation ( $A_{650}$ ) to those at the natural site (A) had significantly higher N concentration and faster decomposition rate as well as release rates of N, P and K. The mass loss patterns for the four litter types fitted the exponential model and the decay constant ( $k$ ) can be well predicted by initial AIF/N. During the decomposition period, N concentration was best related to the percentage of mass remaining of the litters with relatively higher AIF concentrations and lower N concentrations, but the percentage of mass remaining of litters with lower AIF concentrations and higher N concentrations correlates strongly with AIF

concentration. Our study proved that changes in precipitation significantly altered the litter quality, and therefore indirectly changed the decay process of leaf litters.

**Keywords** litter decomposition, precipitation changes, litter substrate quality, *Quercus mongolica*.

### 1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) report emphasized that the elevated  $\text{CO}_2$  concentration in the atmosphere not only elevated the global temperature, but also changed the regional precipitation pattern. Such changes have affected the eco-physiological process of plants and the carbon cycling process of terrestrial ecosystem. Litter is a major component of forest carbon and its decomposition exerts a great influence on the storage of forest carbon and the rates of nutrient return to the soil (Berg, 2000; Liski et al., 2003). Thus, litter plays a key role in controlling the soil nutrient availability and material cycling in the forest (Melillo et al., 1982, 1989; Pan et al., 2004).

Present studies on the issues of global change mainly focus on the response of plants to the elevated  $\text{CO}_2$  environment. Also, there were many studies on how elevated  $\text{CO}_2$  impacts the initial litter quality and decomposition process (Chen et al., 2001; Limpens and Berendse, 2003). Elevated  $\text{CO}_2$  concentration contributes to the increase in the concentrations of lignin or acid-insoluble fraction (AIF), cellulose, phenolic compounds and decrease in the N concentration in the plant tissues, which impedes the litter decomposition (Cotrufo and Ineson, 1996; Chen et al., 2001; King et al., 2001). In addition, changes in other environmental factors especially precipitation can also alter the eco-physiological process of plants. This may cause a corresponding changes in the secondary product and nutrient concentrations in the plant tissues, and therefore alter the litter decomposition and the balance between nutrient release and absorption by plants in the forest ecosystem (Austin and Vitousek, 1998, 2000;

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Limpens and Berendse, 2003; Hobbie and Gough 2004; Semmartin et al., 2004; Liu et al., 2005; Moore et al., 2005). However, the influence of precipitation variation on litter decomposition has not attracted enough attention despite its importance in understanding the interaction between global change and terrestrial ecosystem. Mongolian oak (*Quercus mongolica*) is widely distributed in the temperate region of northeast Asia. It often forms large area of pure Mongolian oak forests in northeast China when the natural forests were heavily exploited. However, there is no study on the indirect effects of precipitation variation on the litter quality and decomposition process in this forest type. The objective of this study is to assess the impact of variation in precipitation on the carbon (C), nitrogen (N), phosphorus (P), potassium (K) and AIF concentrations in Mongolian oak leaf litters and how such changes in litter quality affects the decomposition process of litters in a pure Mongolia oak forest.

## 2 Study area

The study site was in the forest ecosystem research station of Changbai Mountain, Chinese Academy of Sciences, located in Erdao Town, Changbai Mountain Committee of Administration and Development, Jilin Province (42°25'N, 128°05'E). The elevation is 738 m. The climate for this region is characterized by temperate monsoon with annual mean temperature of about 3.0°C and annual precipitation of about 700 mm occurring mainly from June to August. The period from May to September belongs to the growing season. The monthly temperature during the experiment period was presented in Fig. 1. The Mongolian oak seedlings were cultivated in the experimental garden of research station, while the decomposition experiment was conducted in the pure Mongolian oak forest, 2 km near the station. The elevation for the forest is about 720–760 m. Mongolian oak represents over 90% of the total arbor. The average height of trees is about 20 m, and the diameter at the breast height of Mongolian oak is about 25 cm.

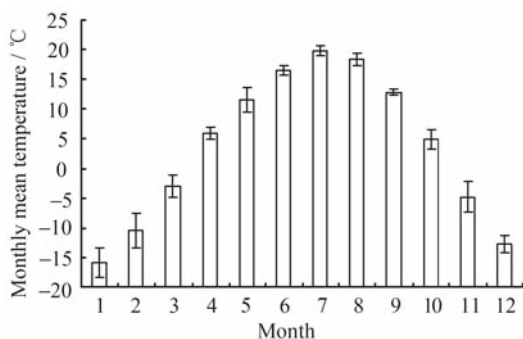


Fig. 1 Monthly mean temperature during Mongolian oak seedling incubation period (1999–2003)

## 3 Materials and methods

### 3.1 Materials

One-year-old Mongolian oak seedlings from the same breed were planted in four 5 m × 1 m seed beds in the spring of 1999, with density of 5 stems/m<sup>2</sup>. Three of the beds were sheltered by glass canopies, which was 2 m off the ground to keep out the rainfall in the growing season and minimize the temperature variation among beds. These three beds were watered twice every month from May to September and the amount of water was comparable to 300, 500 and 700 mm rainfall, respectively. The glass canopies were taken out in the non-growing season. The fourth bed was in the natural state. The actual annual precipitation for each bed was given in Fig. 2.

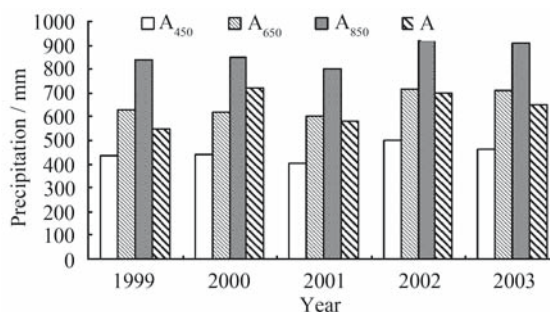


Fig. 2 Actual annual precipitation in the four plots  
Note: A, A<sub>450</sub>, A<sub>650</sub> and A<sub>850</sub> represent the leaf litters from oak saplings receiving normal, 450, 650 and 850 mm precipitation, respectively. The same as below.

In autumn 2003, leaf litters were collected from the seedling growing on the beds receiving 450, 600 and 850 mm of atmosphere precipitation from May to September, and represented by A<sub>450</sub>, A<sub>650</sub>, A<sub>850</sub> and A respectively for abbreviation. The litters were taken back to the laboratory and air-dried at the room temperature to a constant mass. Then, litters from the same bed were fully mixed to generate a homogeneous substrate for each litter type. Subsamples were taken to determine the air-dry to oven-dry (55°C) conversion factors and then reserved for chemical analysis.

### 3.2 Methods

The amount of 4.0 g air-dried litters were put in a 1.0 mm polyethylene mesh litterbag with a size of 15 cm × 20 cm. Litter decomposition experiment was carried out in three sites that were at least 100 m apart from each other. Within each of the three sites selected for litter decomposition assessment, three plots were randomly located yielding a total of nine plots for the study. In early November 2003, 40 litterbags were placed in each plot, ten litter bags for each litter type. The litterbags were placed among the newly formed litter layer to simulate the litter decomposition process. On each

sampling day, one litterbag was collected from each plot per type. Extraneous matters adhering to the litterbag were carefully removed, and they were then dried at 55°C to constant mass and weighed. Collection of litterbags were completed in early November 2003, April 2004, June 2004, August 2004, October 2004, April 2005 and July 2005, corresponding to 0, 150, 210, 270, 330, 510 and 600 days following the start of the experiment.

For chemical analysis, dried samples were milled to pass through a 0.5 mm screen prior to elemental analysis. The concentrations of N and P were calculated using modified Kjeldahl method followed by photometric analysis, and the C concentration was determined using  $K_2Cr_2O_7-H_2SO_4$  method. K concentration was determined using element analyzer (Vario EL III. Elementar. Germany). Ash content in samples was qualified using a muffle furnace. The content of acid-insoluble fraction (AIF) was determined using hot  $H_2SO_4$  digestion method.

Element concentrations were calculated on an ash-free, dry-mass basis. Litter decomposition pattern was calculated using negative exponential decay model

$$X_t/X_0 = B \exp(-kt) \quad (1)$$

where  $X_t$  is the litter mass at time  $t$  (year), and  $X_0$  is the initial litter mass,  $B$  is parameter,  $k$  is decay constant (1/year).

The influences of initial litter variables including N, AIF, C/N and AIF/N on the mass remaining at different decomposing phases were determined using stepwise multiple regression analysis, and the variable that had the highest coefficient value was regarded as the dominant factor controlling litter mass loss. One-way analysis of variance (ANOVA) was used to test the differences among values, and multiple comparisons of means were performed using Duncan's multiple tests at the level of 0.05.

## 4 Results and analysis

### 4.1 Influences of precipitation variation on initial litter quality

Variation in precipitation significantly influenced the initial leaf litter quality (Table 1). Compared with A,  $A_{450}$  had significantly lower total C and AIF concentrations but significantly higher N, P and K concentrations. The difference in total C and N concentrations between  $A_{850}$  and A was not significant, but AIF, P and K concentrations were

significantly higher in  $A_{850}$  than that in A. This suggested that decreasing precipitation will improve the litter quality, while increasing precipitation tends to reduce the litter quality. Although precipitation on beds  $A_{650}$  and A were almost identical,  $A_{650}$  had significantly higher C and N concentrations than A. Changes in C, N and AIF concentrations caused the corresponding changes in C/N and AIF/N. C/N in  $A_{450}$  and  $A_{650}$  were significantly lower than that in A and  $A_{850}$ , and AIF/N in  $A_{450}$  was significantly higher than that in A,  $A_{650}$  and  $A_{850}$ .

### 4.2 Litter mass loss pattern

For all litter types, the mass loss pattern can be classified into slow (0–210 days), fast (210–330 days) and slow (330–600 days) stages (Fig. 3). The differences in percent mass remaining among the four litter types were not significant until after 270 days of decomposition (Fig. 3). The reason is that temperature was low from November to April of the next year (Fig. 1), which impeded the microbial activities and therefore decreased the litter decomposition rates. Higher temperature and precipitation promote the litter decomposition and the differences in percent litter mass remaining among the four litter types. After 270 days, the percent mass remaining of  $A_{450}$  and  $A_{650}$  were significantly lower than that of  $A_{850}$  and A, and  $A_{450}$  had significantly lower percent mass remaining than  $A_{650}$ . The percent mass remaining of  $A_{850}$  was comparable to that of A, suggesting that the influence of differences in the initial litter quality between these two litter types was not strong enough to cause the corresponding differences in percent mass remaining. The percent mass remaining for

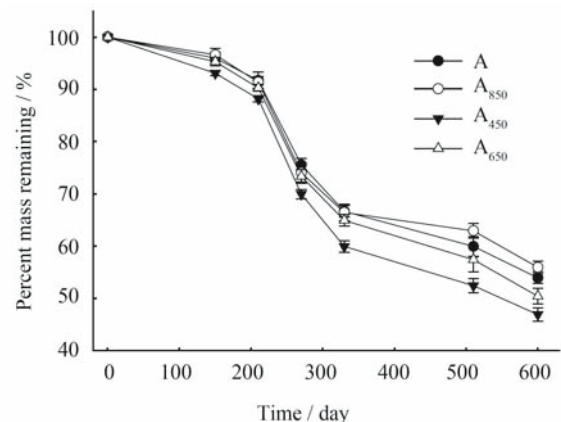


Fig. 3 Percent mass remaining of four types of oak leaves during 600-day incubations

Table 1 Substrate quality of leaf litters produced by oak saplings receiving different precipitations during growing season ( $\pm$  SE)

| Litter type | Total C/( $mg \cdot g^{-1}$ ) | Total N/( $mg \cdot g^{-1}$ ) | Total P/( $mg \cdot g^{-1}$ ) | Total K/( $mg \cdot g^{-1}$ ) | AIF/( $mg \cdot g^{-1}$ ) | C/N   | AIF/N ratio |
|-------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------|-------|-------------|
| A           | 452.1 $\pm$ 2.0a              | 7.1 $\pm$ 0.3a                | 0.50 $\pm$ 0.02a              | 0.82 $\pm$ 0.01a              | 205.2 $\pm$ 2.5a          | 63.66 | 28.87       |
| $A_{450}$   | 421.3 $\pm$ 5.1b              | 11.1 $\pm$ 0.1b               | 0.85 $\pm$ 0.03b              | 1.15 $\pm$ 0.02b              | 176.3 $\pm$ 3.6b          | 37.92 | 16.75       |
| $A_{650}$   | 466.5 $\pm$ 2.2c              | 8.4 $\pm$ 0.1c                | 0.51 $\pm$ 0.01a              | 0.83 $\pm$ 0.01a              | 208.1 $\pm$ 3.3a          | 55.47 | 24.76       |
| $A_{850}$   | 458.4 $\pm$ 4.5a              | 7.2 $\pm$ 0.1a                | 0.71 $\pm$ 0.01d              | 0.94 $\pm$ 0.01c              | 239.4 $\pm$ 2.8c          | 63.61 | 33.19       |

Note: values for each column sharing the same letters are not significantly different ( $p < 0.05$ ) by the Tukey's HSD means separation test.

$A_{450}$ ,  $A_{650}$ ,  $A_{850}$  and A at the end of the study was  $45.3\% \pm 1.95\%$ ,  $48.5\% \pm 1.18\%$ ,  $54.2\% \pm 2.76\%$  and  $52.0\% \pm 1.27\%$ , respectively.

The decomposition constant ( $k$ ) varied greatly among the four litter types (Table 2). The  $k$  value of  $A_{450}$  was significantly higher than that of  $A_{650}$ ,  $A_{850}$  and A, and the  $k$  value of  $A_{650}$  was also significantly higher than that of  $A_{850}$  and A, while there was no significant difference in  $k$  values between  $A_{850}$  and A. The  $k$  values showed a significant relationship with the initial litter quality. The coefficients for the relationships between  $k$  values and the initial N, P and AIF concentrations, C/N, C/P and AIF/N were 0.944 ( $p = 0.056$ ), 0.43 ( $p = 0.56$ ),  $-0.894$  ( $p = 0.106$ ),  $-0.949$  ( $p = 0.051$ ),  $-0.381$  ( $p = 0.619$ ) and 0.996 ( $p = 0.004$ ), respectively. Initial AIF/N showed the most great correlation with  $k$  values, suggesting that it was the best predictor for the litter decomposition rate (Fig. 4).

**Table 2** Decomposition constant ( $k$ ) for different types of oak leaf litters

| Litter type | $k$              | $B$    | $R^2$ | $p$      |
|-------------|------------------|--------|-------|----------|
| A           | $0.41 \pm 0.02a$ | 105.95 | 0.92  | $< 0.01$ |
| $A_{450}$   | $0.50 \pm 0.02b$ | 105.91 | 0.93  | $< 0.01$ |
| $A_{650}$   | $0.45 \pm 0.01c$ | 106.44 | 0.93  | $< 0.01$ |
| $A_{850}$   | $0.38 \pm 0.02a$ | 104.34 | 0.90  | $< 0.01$ |

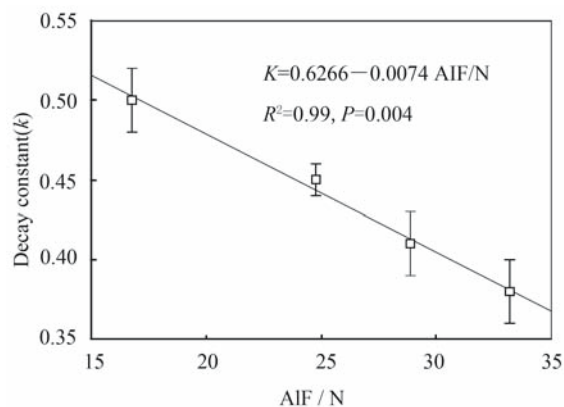
### 4.3 N, P and K dynamics

N was immobilized in all litter types in the first decomposition stage.  $A_{850}$  exhibited the longest N immobilization phase among all the litter types, more than 500 days, followed by A and  $A_{650}$ .  $A_{450}$  showed weak N immobilization phase. At the end of the experiment, the percent N remaining among the four litter types varied significantly and decreased with the following order:  $A_{850} > A > A_{650} > A_{450}$  (Table 3).

**Table 3** Changes in N, P and K percent mass remaining for the four leaf litter types over a 600-day decay period ( $n = 3$ ,  $\pm$  SE)

| Element | Time /day | A                  | $A_{850}$          | $A_{650}$          | $A_{450}$          |
|---------|-----------|--------------------|--------------------|--------------------|--------------------|
| N       | 150       | $101.98 \pm 1.47a$ | $115.19 \pm 2.13b$ | $112.32 \pm 2.35b$ | $99.06 \pm 1.51a$  |
|         | 210       | $101.29 \pm 2.15a$ | $113.07 \pm 2.37b$ | $110.27 \pm 2.55b$ | $101.86 \pm 1.68a$ |
|         | 270       | $105.26 \pm 2.26a$ | $120.64 \pm 4.05b$ | $102.18 \pm 3.14a$ | $88.21 \pm 1.99c$  |
|         | 330       | $99.24 \pm 4.31a$  | $132.33 \pm 4.38b$ | $79.77 \pm 2.89c$  | $83.81 \pm 2.32d$  |
|         | 510       | $99.66 \pm 3.59a$  | $118.48 \pm 3.16b$ | $73.13 \pm 3.36c$  | $61.19 \pm 1.88d$  |
|         | 600       | $85.65 \pm 4.13a$  | $95.26 \pm 3.59b$  | $58.19 \pm 4.06c$  | $50.37 \pm 2.59d$  |
| P       | 150       | $111.36 \pm 2.62a$ | $99.04 \pm 2.17b$  | $104.88 \pm 2.48c$ | $96.38 \pm 1.93b$  |
|         | 210       | $98.14 \pm 2.98a$  | $113.69 \pm 2.69b$ | $98.78 \pm 3.35a$  | $96.66 \pm 2.24a$  |
|         | 270       | $107.51 \pm 3.22a$ | $148.26 \pm 6.51b$ | $114.34 \pm 2.89c$ | $101.37 \pm 3.36a$ |
|         | 330       | $123.28 \pm 4.31a$ | $130.09 \pm 3.46a$ | $109.68 \pm 2.82b$ | $81.08 \pm 2.55c$  |
|         | 510       | $110.53 \pm 2.98a$ | $116.47 \pm 3.18a$ | $98.60 \pm 2.91b$  | $72.33 \pm 2.18c$  |
|         | 600       | $85.65 \pm 4.13a$  | $95.26 \pm 3.59b$  | $58.19 \pm 4.06c$  | $50.37 \pm 2.59d$  |
| K       | 150       | $97.56 \pm 1.53a$  | $99.40 \pm 1.07a$  | $99.89 \pm 0.98a$  | $95.30 \pm 0.93a$  |
|         | 210       | $96.05 \pm 1.95a$  | $97.88 \pm 1.58a$  | $98.33 \pm 1.86a$  | $86.38 \pm 1.55b$  |
|         | 270       | $85.38 \pm 2.43a$  | $88.56 \pm 1.52a$  | $90.15 \pm 1.92a$  | $75.94 \pm 2.67b$  |
|         | 330       | $80.04 \pm 3.35a$  | $84.38 \pm 2.87a$  | $83.11 \pm 2.33a$  | $68.76 \pm 3.01b$  |
|         | 510       | $74.65 \pm 2.90a$  | $76.77 \pm 3.41a$  | $72.45 \pm 2.88a$  | $55.89 \pm 2.10b$  |
|         | 600       | $56.12 \pm 3.08a$  | $58.32 \pm 3.38a$  | $50.03 \pm 2.78b$  | $32.72 \pm 3.26c$  |

Note: the same letter in each row means no significant difference in the litter N, P and K remaining at 0.05 probability level.



**Fig. 4** Relationships between litter decay constant ( $k$ ) and initial AIF/N

P also showed marked immobilization phase.  $A_{850}$  and A did not exhibit net P mineralization phase through the study period. P in  $A_{650}$  was immobilized at the first decay stage and mineralized at the late decay stage.  $A_{450}$  showed weak P immobilization at the first phase. The percentage of P remaining was significantly lower in  $A_{450}$  than that in  $A_{650}$  at the end of the study (Table 3). K was mineralized continuously in all litter types during the whole study and its mineralization rate was higher than that of N and P. The difference in percent P remaining among  $A_{850}$ , A and  $A_{650}$  was not significant before 510 days, but percent P remaining for  $A_{450}$  was significantly lower than that for  $A_{850}$ , A and  $A_{650}$  after 150 days of decomposition.

### 4.4 Relationships between percent remaining of litter mass and other litter chemical indices over time

The percentage of litter mass remaining was significantly related to N, P and AIF concentrations, C/N, C/P and AIF/N over time (Table 4). However, the relationships between litter

**Table 4** Correlation coefficients of litter percent mass remaining and chemical indices

| Litter type      | N concentration | P concentration | AIF concentration | C/N    | C/P   | AIF/N  |
|------------------|-----------------|-----------------|-------------------|--------|-------|--------|
| A                | -0.90**         | -0.77*          | -0.76*            | 0.88** | 0.55  | -0.80* |
| A <sub>450</sub> | -0.65           | -0.80*          | -0.92**           | 0.76*  | 0.66  | -0.86* |
| A <sub>650</sub> | -0.62           | -0.71           | -0.91**           | 0.77*  | 0.83* | -0.49  |
| A <sub>850</sub> | -0.92**         | -0.82*          | -0.85*            | 0.90** | 0.78* | -0.81* |

Note: \* refers to  $p < 0.05$ ; \*\* refers to  $p < 0.01$ .

mass remaining and the chemical indices noted above varied greatly among litter types. The percent remaining of A and A<sub>850</sub> showed the most significant relationships with the N concentration over time. In contrast, the percent remainings of A<sub>450</sub> and A<sub>650</sub> were not significantly related to the N concentration. The mass remainings for all litter types were significantly related with AIF concentration and C/N over time, but the percent remaining of A<sub>450</sub> and A<sub>650</sub> showed less greater relationships with C/N and higher relationships with AIF compared with that of A<sub>850</sub> and A. Besides A<sub>650</sub>, the percent remaining of other three litter types were significantly related to the P concentration and AIF/N over time.

## 5 Discussion

### 5.1 Impacts of precipitation variation on the initial litter quality

Previous studies suggested that long-term changes in CO<sub>2</sub> concentration, soil nutrient availability, temperature and precipitation could alter the initial litter quality (Cotrufo and Ineson, 1996; Liao et al., 1997; Austin and Vitousek, 1998; Austin and Vitousek, 2000; King et al., 2001; Hobbie and Gough, 2004; Pan et al., 2004). Litter decomposition conducted in natural forests in Hawaii showed that N and lignin concentrations in *Metrosideros polymorpha* leaf litter increased with increasing precipitation, while P concentration decreased with increasing precipitation (Austin and Vitousek, 2000). In this study, AIF concentration increased with the increment in precipitation which was generally consistent with the study conducted in Hawaii (Austin and Vitousek, 2000), but the N concentration decreased with increasing precipitation and P concentration did not show consistent change pattern with the increasing precipitation. This discrepancy suggested that the response of the initial litter quality to changes in precipitation varied from plant species and elements. Many studies showed that elevated CO<sub>2</sub> concentration decreased the N concentration and increased the AIF and lignin concentrations in plant tissues (Cotrufo and Ineson, 1996; Chen et al., 2001; King et al., 2001). Our study suggested that changes in precipitation can exert similar influences on litter quality as CO<sub>2</sub> does. Because global changes involve the changes in both precipitation and CO<sub>2</sub>, the following questions may be generated. How do the changes in both precipitation and CO<sub>2</sub> concentration affect the litter quality? Do the changes in litter quality offset or exacerbate

the direct impact of precipitation or CO<sub>2</sub> or both on the litter decomposition?

Although the precipitation on beds A and A<sub>650</sub> were similar, the C and N concentrations in A<sub>650</sub> was still significantly higher than that in A. This may be attributed to the differences in the precipitation pattern. Mongolia oak seedlings living on bed A<sub>650</sub> received periodically precipitation, while seedlings living on bed A received irregularly natural precipitation. Such differences in the pattern of precipitation may change the physiological process of the Mongolian oak seedlings, and consequently alter the litter quality.

### 5.2 Influences of initial litter quality on decomposition rate

Joseph et al. (2002) studied the decomposition of seven litter types in longleaf pine forest in North America and found that initial C/N, AIF/N and P were significantly related to the litter decomposition rate. In this study, both initial C/N and AIF/N were closely related to litter decomposition constant ( $k$ ), which was consistent with the report of Joseph et al. (2002). However, the correlation analysis results in this study were also different from that of the study conducted in western Oregon, in which a significant relationship between C/P and  $k$  values and a weak relationship between C/N and  $k$  values were found (Valachovic et al., 2004). It should be noted that the differences among the initial litter quality in this study come from the same species, while for the studies of Joseph et al. (2002) and Valachovic et al. (2004), such differences were generated by different species. The similarity in the response of  $k$  values to initial litter quality between our study and that of Joseph et al. (2002) and Valachovic et al. (2004) suggested that the chemical characteristics of litters play a dominant role in controlling litter decomposition (Moore et al., 1999; Limpens and Berendse, 2003). However, Prescott et al. (2004) reported that lignin was a good predictor of mass loss only during the first year in Canada, and percent mass remaining for litters from different species had a tendency of being the same after over five years' decomposition. Thus, further researches are needed to understand the relationship between the initial litter quality and litter mass loss.

### 5.3 Nutrient release dynamics

Many studies have reported that litters of N and P were immobilized in the first decomposition phase and mineralized

in the late decomposition phase (Melillo et al., 1989; Austin and Vitousek, 1998; Latter et al., 1998; King et al., 2001; Liu et al., 2005), which was generally consistent with our results. Litters with higher N or P concentration and lower AIF concentration exhibited shorter or even no N or P immobilization phase (Taylor et al., 1989; Tian et al., 1992). This was because litters with higher N concentration had lower C/N, which made it reach the critical C/N, at which net N mineralization started at an earlier time when compared with litters with lower N concentration. In addition, the existence of AIF shielded other degradable fractions against the invasion of microorganism, and therefore impeded the decomposition and N release rate (Berg et al., 1993; Berg, 2000). In this study, N release rate and immobilization time can be well explained by the initial AIF/N, suggesting that N release was controlled by both N and AIF concentrations. P release rate was not significantly related to the initial litter quality, suggesting that the P release was controlled by different factors from those of N. K was mineralized continuously during the study, which was consistent with other studies (Vitousek, 1984; Joseph et al., 2002). However, there have been no reasonable explanations for this phenomenon.

The relationships between percent litter mass remaining and chemical indices through the time varied from litter types. The percent mass remaining of A and A<sub>850</sub> showed the highest relationships with N concentration, while the percent mass remaining of A<sub>450</sub> and A<sub>650</sub> were most significantly related to AIF concentration. The reason may be that A and A<sub>850</sub> have lower N concentrations which cannot provide sufficient N supply for the decomposer. Thus, the decompositions of A and A<sub>850</sub> were more easily limited by N. In contrast, higher N concentration in A<sub>450</sub> and A<sub>650</sub> can meet the demand of decomposer for N. This made AIF appear to be major limiting factors for A<sub>450</sub> and A<sub>650</sub>. Our study also showed that percent litter mass remaining for the four litter types were significantly related to C/N over time. This was different from the report of Joseph et al. (2002), in which the percent mass remaining for all litter types were significantly related to N concentration.

This study indicated that variation in precipitation will change the initial litter quality of Mongolian oak and therefore alter its decomposition process and nutrient release rates indirectly. The arid environment will make Mongolian oak produce high-quality litters (higher N concentration and lower AIF concentration), and humid environment make Mongolia oak produce low-quality litters (lower N concentration and higher AIF concentration). Such changes may to some extent mitigate the direct effects of precipitation variation on the processes of litter decomposition.

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