



# Decomposition dynamics and ecological stoichiometry of *Quercus acutissima* and *Pinus densiflora* litter in the Grain to Green Program Area of northern China

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**Abstract** Litter decomposition and ecological stoichiometry of nutrient release is an important part of material cycling and energy flow in forest ecosystems. In a study of the ecological stoichiometry and nutrient release during litter decomposition in a pine–oak forest ecosystem of the Grain to Green Program (GTGP) area of northern China, a typical pine and oak species (*PDS*: *Pinus densiflora* Sieb., *QAC*: *Quercus acutissima* Carr.) were selected in the Taiyi Mountain study area. The ecological stoichiometry characteristics of carbon (C), nitrogen (N) and phosphorus (P) and litter decomposition dynamics were studied by field sampling and quantitative analyses. The results showed the following. (1) The decomposition dynamics of both litters

was slow-fast-slow. The most important climatic factor affecting the litter decomposition rate from May to October was precipitation and temperature from November to April of the following year. (2) Throughout the 300-day study, in both litters, C of the two litters was released, N first accumulated and was then released, and P exhibited a release-accumulate-release pattern. (3) C:P was significantly higher than C:N and N:P ( $p < 0.05$ ); the C:N of *PSD* litter was higher than that of *QAC* ( $p < 0.05$ ), but the N:P of *QAC* litter was higher than that of *PSD* litter ( $p < 0.05$ ). The C:N of both litters was very high in the study area, indicating that the nutrient release ability during litter decomposition in the two typical pine–oak forest ecosystems was relatively weak; therefore, more attention should be paid to nitrogen-fixing species and mixed forests in the GTGP area of northern China.

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**Keywords** Decomposition dynamics · Ecological stoichiometry · Litter · *Pinus densiflora* · *Quercus acutissima* · Grain to Green Program (GTGP)

## Introduction

Litter decomposition in terrestrial ecosystems is an important part of the global carbon budget and is mainly controlled by climate, litter quality and soil biota (Li et al. 2010; Chen et al. 2016). The forest ecosystem is the main body of terrestrial ecosystems and plays an important role in maintaining the stability of the biosphere and improving the environment (Zhao et al. 2004). Litter is an important contributor for biological yield, material cycling and energy flow in forest ecosystems, and its decomposition plays an important role in material circulation, nutrient balance and soil fertility maintenance in forest ecosystems

(Pan et al. 2004; Das and Mondal 2016). The dynamic changes in nutrient elements in litter are closely related to the litter decomposition rate, which directly determines the nutrient status of the ecosystem. Therefore, research on litter decomposition has become an important aspect in the study of forest ecosystem structure and function. During the process of decomposition, the characteristics of the release of nutrient elements from litter were closely related to the characteristics of the elements (Zhao et al. 2006).

Ecological stoichiometry is an important method to study biogeochemical cycling and ecological processes of organic carbon (C), total nitrogen (N), and total phosphorus (P) (He and Han 2010). Because C, N and P are the most basic nutritional elements for the growth of vegetation, their ecological stoichiometry and is important for determining plant growth rates and nutrient-use efficiencies and assessing limiting elements (Zhou et al. 2010; Niu et al. 2013). Among studies of variations in the the decomposition rate and ecological stoichiometry of litter in different forest vegetation types, temperature and freeze–thaw have been found to be key factors affecting litter decomposition in the Eastern Tibetan Plateau of China (Xu et al. 2016). The nutrient composition of litter and the environment of a site significantly influence litter decomposition rate, but the composition of litter plays a more important role (Xie et al. 2017). In freshwater marshes of Northeast China, the accumulation of N caused by climate warming and vegetation community change has accelerated litter decomposition (Zhang et al. 2017). Marcescent litter can indirectly reduce the C:N of leaves with poor decomposition abilities, making the stoichiometry of soil microbes obviously different and the litter easier to decompose (Angst et al. 2017). The litter decomposition rate of nitrogen-fixing tree species is related to the initial C:P, C:N, N, P and Ca, while that of non-nitrogen-fixing tree species is related only to the initial Ca value (Sayad et al. 2015). In recent years, the relationship between the litter decomposition rate and the ecological stoichiometry characteristics in forest ecosystems and the mechanisms that influence this relationship have received increasing attention.

There are about 46 million ha of sloping fields in China, accounting for 35.1% of the total cultivated land. The area of sloping fields in the Huaihe River Basin is 840,000 ha, to which sloping fields in the Taiyi Mountain area (Mountain Tai and Mountain Yimeng area) contribute 470,000 ha (> 55% of the total). The Taiyi Mountain area is a typical area of the GTGP (Grain to Green Program) in northern China, and pine–oak forest is an important forest vegetation type. Research on these pine–oak forest ecosystems has mainly focused on the effects of climatic factors on forest growth, forest ecological hydrology, soil improvement and spatial variation characteristics of soil elements such as C, N, and P (Li et al. 2003; Zhang et al.

2015a; Liu et al. 2017), while decomposition rates and stochastic characteristics of forest litter has received far less study. Without such information, it is difficult to accurately determine the effects of the GTGP on the nutrient-release mechanisms during litter decomposition and quantitatively evaluate benefits to the environment. We therefore selected a typical pine and oak species, *QAC* (*Quercus acutissima* Carr.) and *PSD* (*Pinus densiflora* Sieb.), in the Taiyi Mountain area and used fixed-point field sampling and quantitative laboratory analyses to study the ecological stoichiometry, loss and dynamics of C, N, and P and the *QAC* and *PSD* litter decomposition dynamics. The nutrient release dynamics of litter during litter decomposition in the pine–oak forest ecosystem helps clarify the availability of C, N and P to the vegetation of the GTGP. This research provides a scientific basis and reference for the quantitative evaluation of the ecological benefits and the study of ecological stoichiometries during the development of the GTGP in the Taiyi Mountain area of China.

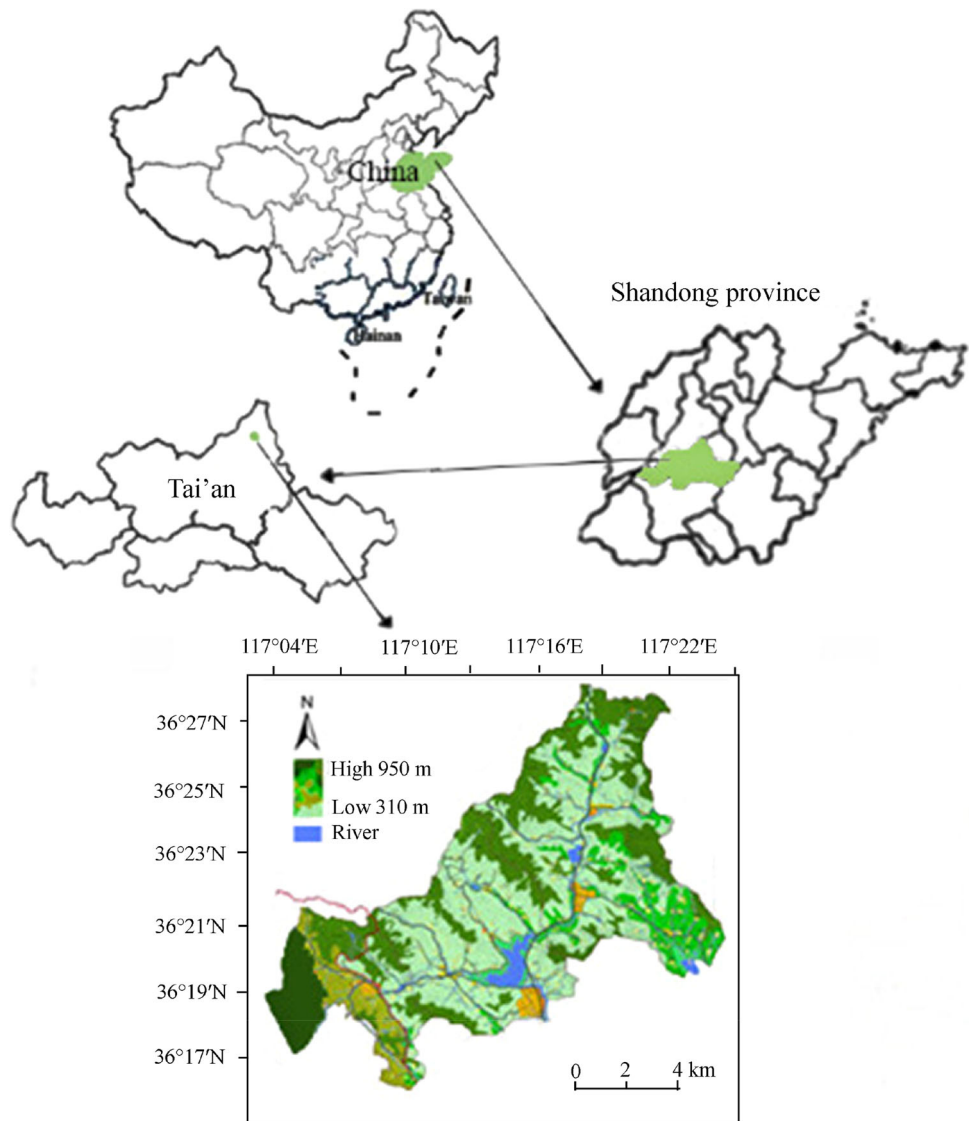
## Materials and methods

### Site description

The study area in the Taishan Forest Ecosystem Research Station (117°04′–117°22′E, 36°17′–36°27′N) is a typical mountainous area in northern China (Fig. 1). The altitude ranges from 310 to 950 m asl (mean 530 m). The climate is warm temperate semi-humid monsoon, and annual average air temperature is 18.5 °C. The mean annual precipitation is approximately 727.9 mm, with 75% of the rainfall between June and September. The frostless season is 196 days. The soil type is brown soil (Table 1). The vegetation types are coniferous forests and deciduous broad-leaved forests in the warm temperate zone, and the main arbor species include *Quercus acutissima* Carr., *Pinus densiflora* Sieb., *Larix kaempferi* (Lamb.) Carr., *Castanea mollissima* Bl. And *Robinia pseudoacacia* L.

### Experimental design and sampling

Litter samples were collected in November 2015 and 2016. In the survey region, we first selected forest lands of *QAC* (30 years) and *PSD* (25 years) as the sampling areas (100 × 100 m), which have similar altitudes, coverages and ages. Three sampling plots (2 × 2 m) were established in each of the upper, middle and lower sides of each sampling area of the *QAC* and *PSD* forests; thus, complete litter was collected from 18 plots and brought back to the laboratory. The surface sludge of litter was washed with

**Fig. 1** Map and elevations of study area**Table 1** Basic characteristics of study area

Species	Slope (°)	Slope aspect	Soil pH	Soil thickness (cm)	Soil type	Litter thickness (cm)	Canopy density	Density (plant ha <sup>-1</sup> )
<i>QAC</i>	25.2	Southern	6.2	34.2	Brown	30	0.7	625
<i>PDS</i>	24.8	Southern	6.5	35.5	Brown	27	0.7	653

*QAC* *Quercus acutissima* Carr., *PDS* *Pinus densiflora* Sieb.

distilled water, dried to constant mass at 65 °C, and bagged (20 g/bag). The litter decomposition bags were fixed in the corresponding stand square, and the soil surface layer depth was 0–10 cm. The bags were fixed in April 2016 and 2017, and three bags were collected from each plot on the same dates in May, June, July, August, September, October, November, and March of the following year. The litter was washed, dried, and weighed, then calculated the quantity of litter loss and litter decomposition rate. These samples

were ground in a 0.1 mm sieve and stored in sealed polyethylene bags for C, N and P analyses.

The litter C content was determined using the K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> oxidation–external heating method, the litter N content using the H<sub>2</sub>SO<sub>4</sub>–H<sub>2</sub>O<sub>2</sub> digestion method, and the litter P content using the Mo–Sb antispectrophotography method (Bao 2010).

Air temperature and precipitation were determined using a CR3000 automatic weather station (Campbell Scientific,

Logan, UT, USA), which automatically recorded data daily and every 10 min. Data were collected every 30 days.

## Statistical analyses

The litter decomposition rate was determined by the “quality loss rate”. The quality loss of *QAC* and *PSD* litter was the average of the losses of three decomposition bags in each sampling plot. The quality loss rate refers to the dry mass loss of litter after decomposition divided by the initial dry mass of litter as follows (Li et al. 2015):

$$D = (W_t/W_0) \times 100, \quad (1)$$

where  $D$  is quality loss rate (%),  $W_t$  is the quantity of litter loss after decomposition time  $t$  (g), and  $W_0$  is the initial quantity of the sample (20 g).

The accumulation or release of elements during litter decomposition was expressed as the nutrient accumulation index (NAI) as follows (Yang et al. 2006):

$$NAI = M_t X_t / (M_0 X_0) \times 100, \quad (2)$$

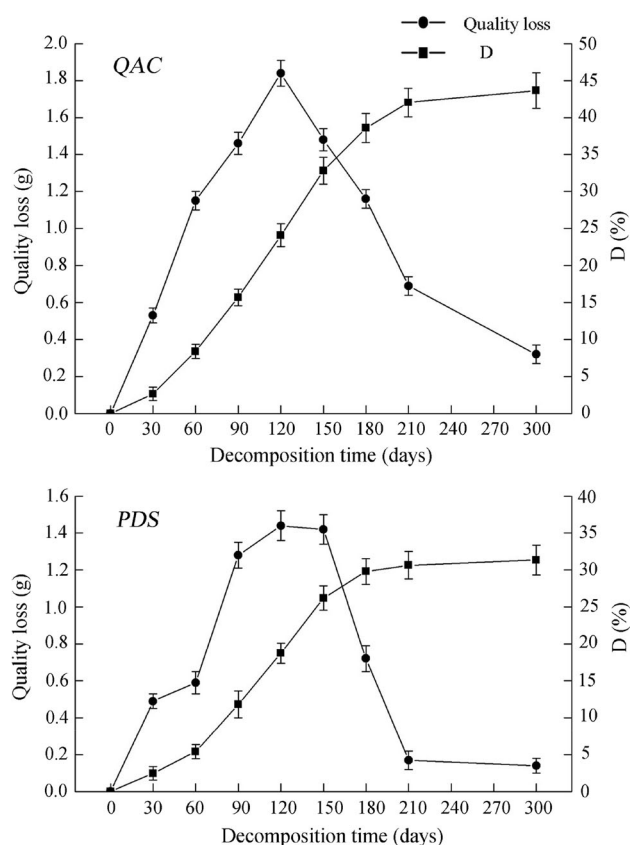
where NAI is nutrient accumulation index,  $M_t$  is the dry mass in the decomposition bag (g) at time  $t$ ,  $X_t$  is the element content of the litter at time  $t$  ( $\text{g kg}^{-1}$ ),  $M_0$  is the initial mass of the sample (20 g),  $X_0$  is the initial element content ( $\text{g kg}^{-1}$ ).  $NAI < 100\%$  indicates net release of the element;  $NAI > 100\%$  indicates net accumulation of the element.

Differences in the concentrations or stoichiometric ratios among the C, N and P in the litter were analyzed by a one-way analysis of variance (ANOVA), and treatment means were compared using least significant difference (LSD) as necessary. Data exhibited non-normal distribution in the present study. A Pearson correlation analysis was performed on the litter decomposition rate and the C:N, C:P, and N:P in the litter, and the differences were considered significant at  $p < 0.05$ . The analyses were performed with the SPSS 19.0 software (IBM, Armonk, NY, USA), and maps were made by OriginPro 8.6 (OriginLab, Northampton, MA, USA).

## Results

### Decomposition dynamics of *QAC* and *PSD* litter

Throughout the observation period (300 days), the litter decomposition dynamics of *QAC* and *PSD* were slow-fast-slow (Fig. 2). The main decomposition of *QAC* litter occurred between 30–210 days (88% of total loss, and the main decomposition of *PSD* litter occurred between 60–180 days (> 76% of total loss). For *QAC* and *PSD*, the total quantity loss was 43.65% and 31.35%, respectively, of



**Fig. 2** The quality loss and quality loss rate ( $D$ ) of *Quercus acutissima* (*QAC*) and *Pinus densiflora* (*PDS*) litter during decomposition over time

the initial quantity after 300 days of decomposition, and the quality loss rate ( $D$ ) was 0.1455%/d and 0.1045%/d, respectively (Table 2). The  $D$  of the *QAC* litter was higher than that of the *PSD* litter.

**Table 2** Quality loss rate ( $D$ ) of *Quercus acutissima* (*QAC*) and *Pinus densiflora* (*PDS*) litter during decomposition over time

Decomposition times (days)	$D$ (%)	
	<i>QAC</i>	<i>PDS</i>
0	0.00 ± 0.00	0.00 ± 0.00
30	2.65 ± 0.31	2.45 ± 0.31
60	8.40 ± 0.95	5.40 ± 0.46
90	15.7 ± 1.12	11.80 ± 0.99
120	24.10 ± 1.53	18.75 ± 1.37
150	32.8 ± 1.81	26.20 ± 1.64
180	38.60 ± 1.96	29.80 ± 1.73
210	42.05 ± 2.34	30.65 ± 1.85
300	43.65 ± 2.39	31.35 ± 2.02

## Dynamics of C, N and P contents in *QAC* and *PSD* litter

Throughout the 300 days, the litter N contents of the two species differed significantly, but the litter C and P contents did not (Table 3) ( $p < 0.05$ ).

The C content of the *QAC* litter decreased rapidly to 0.82 times the initial content after 60 days and then increased at a relatively slow rate. After 120 days, the C content of the litter was 0.88 times the initial content, and then it decreased slowly. The variation in the C content of *PSD* litter was similar to that of *QAC*. The C content of the litter was 0.78 times the initial content at 90 days and then increased; the C content was 0.92 times the initial content at 150 days, and then it decreased slowly (Fig. 3a).

The N content of the *QAC* litter increased to 1.42 times the initial content at 180 days and then decreased rapidly. At 210 days, the N content of the litter was 0.89 times the initial content and then increased slowly. The variation in the N content in the *PSD* litter was similar to that in the *QAC* litter; it increased to 1.55 times the initial content at 150 days and then began to decrease. At 210 days, the litter N content was 0.98 times the initial content and then increased slowly (Fig. 3b).

The P content of *QAC* litter rapidly decreased to 0.81 times the initial content at 30 days and then increased at a relatively fast rate. At 210 days, the litter P content was 1.98 times the initial content and then decreased. The P content in *PSD* litter increased to 1.53 times the initial content at 150 days and then began to decrease slowly (Fig. 3c).

Changes in the elements and absolute value of the nutrient accumulation index (NAI) occurred during the litter decomposition. With decomposition, litter accumulate or releases different elements, changing stoichiometric ratios (Wang et al. 2010). The NAI values for C in the *QAC* and *PSD* litter were 44.12–87.04% and 57.55–86.38%, respectively, during the decomposition period (Table 4), indicating a net release of C. The NAI values for N in the *QAC* litter varied from 100.88 to 102.38% after 60 days

and then varied from 52.15 to 98.57%. The NAI values for the N in the *PSD* litter varied from 101.18 to 114.06% after 180 days of decomposition and then from 68.55 to 74.07%. A net accumulation of N first occurred during decomposition and was followed by a net release of N. The NAI of P in the *QAC* litter was 78.87% after 30 days of decomposition, and variation ranges were 124.09–133.68% and 58.58–90.27%. The NAI of P in the *PSD* litter varied from 90.96 to 93.32% after 30 days of decomposition, and variation ranges were 103.42–112.71% and 81.66–87.18%. These results showed that P exhibited a release-accumulate-release pattern in litter during decomposition.

## Dynamics of ecological stoichiometries of the C, N and P contents in *QAC* and *PSD* litter

Throughout the 300-day decomposition, the C:N of *PSD* litter was higher than that of *QAC* litter ( $p < 0.05$ ), but the N:P of *QAC* litter was higher than that of *PSD* ( $p < 0.05$ ) (Table 3). C:P did not differ significantly between the species.

In addition, the variation trends of C:N in the litter of *QAC* and *PSD* were similar. The C:N of *QAC* litter decreased to 0.58 times the initial C:N at 180 days and then increased rapidly. At 210 days, the C:N was 0.88 times as high as the initial one and then began to decrease slowly. The litter C:N of *PSD* decreased to 0.61 times the initial C:N at 150 days and then increased rapidly. At 210 days, the C:N was 0.85 times that of the original value and then began to decrease slowly. The C:N of *QAC* and *PSD* litter decreased at varying degrees at the end of decomposition, and the C:N were 80.7% and 77.7% of the initial values, respectively (Fig. 4a).

The C:P of *QAC* litter increased at first, then decreased rapidly to 1.10 times the initial value at 60 days, and then decreased at a lower rate. At 150 days, the litter C:P was 0.43 times that of the initial value and then began to increase slowly. The C:P of *PSD* litter decreased to 0.58 times of the initial value at 120 days and then began to

**Table 3** The C, N and P contents and ecological stoichiometry characteristics of *Quercus acutissima* (*QAC*) and *Pinus densiflora* (*PDS*) litter

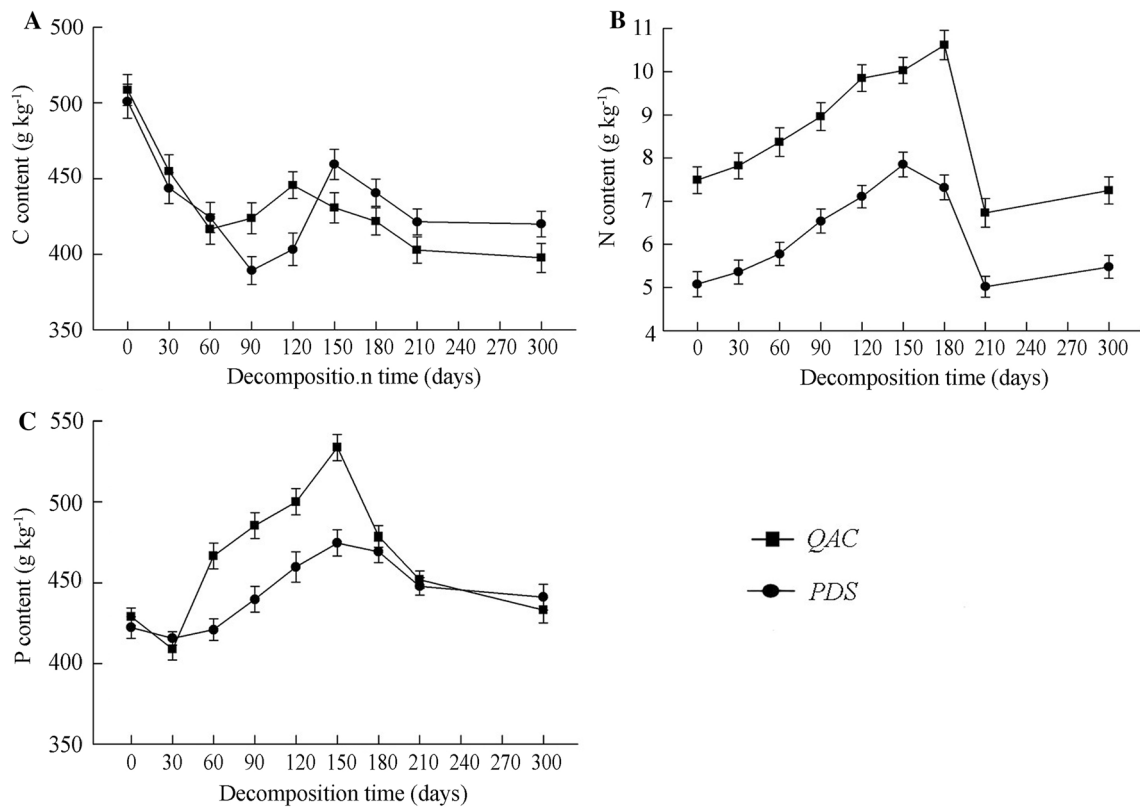
	Species	C (g kg <sup>-1</sup> )	N (g kg <sup>-1</sup> )	P (g kg <sup>-1</sup> )	C:N	C:P	N:P
Initial value	<i>QAC</i>	508.52 ± 10.21a	7.49 ± 0.31a	0.79 ± 0.04a	67.89 ± 1.62a	643.7 ± 11.21a	9.48 ± 0.31a
	<i>PDS</i>	501.04 ± 10.63a	5.08 ± 0.29b	0.74 ± 0.05a	98.63 ± 1.98b	677.08 ± 13.21a	6.86 ± 0.24b
Observed average	<i>QAC</i>	433.56 ± 17.8a	8.57 ± 0.55a	1.06 ± 0.045a	51.74 ± 1.1a	441.51 ± 8.8a	8.42 ± 0.23a
	<i>PDS</i>	433.63 ± 11.7a	6.17 ± 0.6b	0.95 ± 0.039a	72.26 ± 1.6b	468.06 ± 9.5a	6.66 ± 0.19b
Global value*	–	367.4	10.9	0.85	50.1	659.00	18.3

Different letters meant significant difference among different species at  $P < 0.05$

The global value\* come from some references that some other researchers have studied

*QAC Quercus acutissima* Carr., *PDS Pinus densiflora* Sieb.





**Fig. 3** Dynamics of C, N and P contents of *Quercus acutissima* (QAC) and *Pinus densiflora* (PDS) litter during decomposition over time

**Table 4** Nutrient accumulation index (NAI) of C, N and P of *Quercus acutissima* (QAC) and *Pinus densiflora* (PDS) litter during decomposition over time

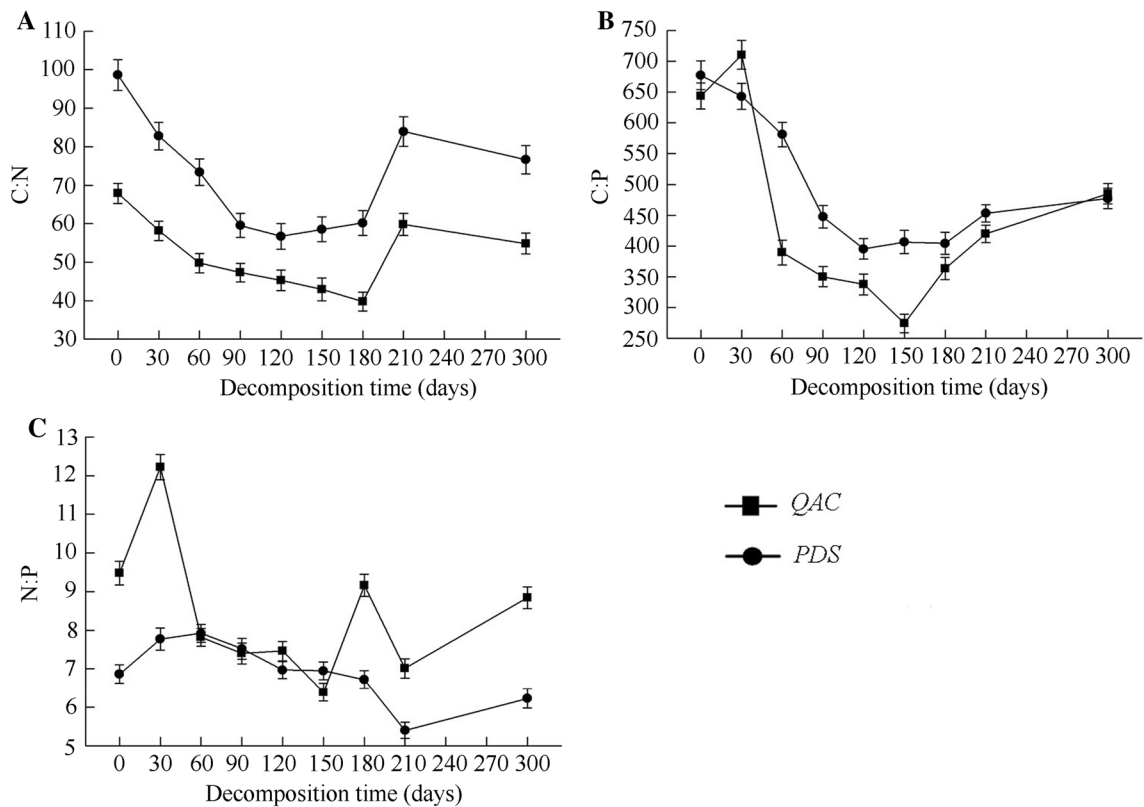
Decomposition duration (days)	QAC			PDS		
	C (%)	N (%)	P (%)	C (%)	N (%)	P (%)
0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
30	87.04 ± 2.07	101.64 ± 2.19	78.87 ± 1.73	86.38 ± 2.02	102.93 ± 1.98	90.96 ± 2.05
60	75.06 ± 1.82	102.38 ± 2.03	124.09 ± 2.08	80.10 ± 1.93	107.64 ± 2.03	93.32 ± 1.86
90	70.28 ± 1.85	100.53 ± 1.97	129.17 ± 1.90	68.52 ± 1.87	113.56 ± 2.17	103.70 ± 1.92
120	66.56 ± 1.73	99.88 ± 1.92	126.90 ± 2.01	65.4 ± 1.81	113.73 ± 1.99	112.01 ± 2.08
150	56.97 ± 1.86	90.08 ± 1.94	133.68 ± 2.13	67.67 ± 1.73	114.06 ± 1.93	112.71 ± 2.13
180	50.98 ± 1.79	87.17 ± 1.83	90.27 ± 1.72	61.75 ± 1.80	101.18 ± 1.82	103.42 ± 1.91
210	45.97 ± 1.71	52.15 ± 1.59	70.52 ± 1.81	58.34 ± 1.72	68.55 ± 1.78	87.18 ± 1.89
300	44.12 ± 1.42	54.63 ± 1.61	58.58 ± 1.56	57.55 ± 1.58	74.07 ± 1.79	81.66 ± 1.87

The numbers in Table 4 are the means of the two years (2016–2017). The NAI is the nutrient accumulation index

increase slowly. The C:P in QAC and PSD litter were equal to 75.32% and 70.48% of the initial values at the end of decomposition, respectively (Fig. 4b).

The N:P of QAC litter fluctuated greatly during the 300 days, increasing rapidly to 1.29 times the initial value after 30 days and then dropped quickly. At 60 days, the litter N:P was 0.82 times the original and then began to change at a lower rate. After sharp fluctuations at

150–210 days, the N:P uniformly increased. The N:P of PSD litter increased slowly to 1.15 times the initial value at 60 days and then began to fluctuate at different rates, which was 0.78 times as high as the initial values at 210 days, and then increased at a lower rate. After 300 days, the N:P in QAC and PSD litter had decreased to 93.25% and 90.82%, respectively, of the initial values (Fig. 4c).



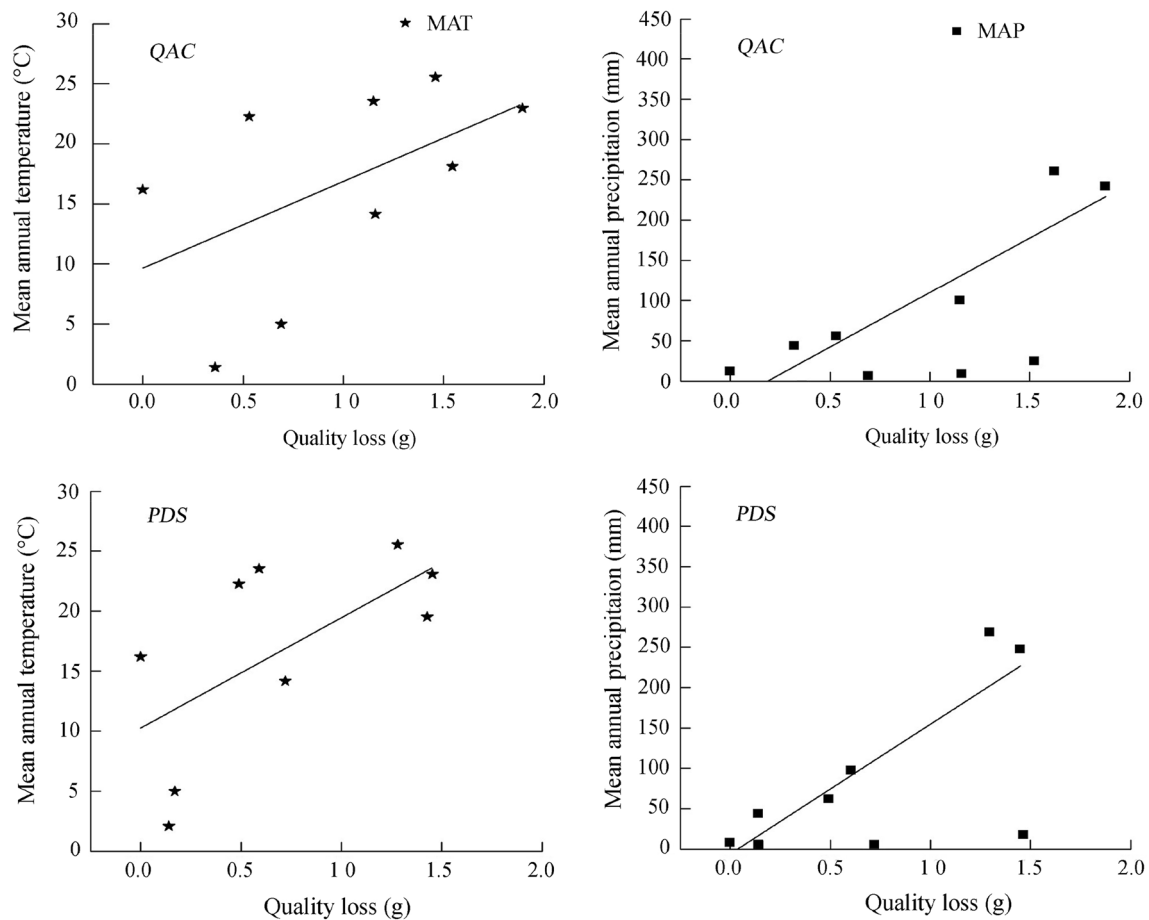
**Fig. 4** Dynamics of ecological stoichiometries of C, N and P of *Quercus acutissima* (QAC) and *Pinus densiflora* (PDS) litter during decomposition over time

## Discussion

### Effects of environmental factors on decomposition of QAC and PSD litter

As a part of forest ecosystem productivity, the litter decomposition rate is the main determinant of surface biomass and nutrient contents in forests. Litter decomposition is mainly controlled by climate, litter quality and soil biota (Wang et al. 2016). Microorganisms, an important source of soil enzymes, are thus the main decomposers (Aon et al. 2001; Wu et al. 2006a). Climate is considered the most important determinant of the litter mass loss rate (Dorrepaal et al. 2005; Xu et al. 2009), with temperature and precipitation the most important (Gao et al. 2004). Temperature, as a leading factor affecting life processes, has an important influence on microorganism abundance and enzyme activities and thus on litter decomposition (Bai et al. 1999). Throughout the 300 days, the decomposition rate of QAC and PSD litter increased with increasing temperature; however, the maximum litter decomposition rate appeared in September, and not in July and August when the temperature was highest (Fig. 5), which indicated that the litter decomposition was affected not only by temperature but also by precipitation. The litter

decomposition mainly depends on the relative relationship between temperature and precipitation (heat and humidity) (Wu et al. 2006b); when the temperature is high and humidity low, the decomposition is rapid, but slow at low temperatures and high humidity. Over-wetting or anaerobic conditions can inhibit the activities and decomposition processes of soil plants and animals (Song et al. 2012). In our study, frozen water in the soil melted in April and May, so soil moisture was relatively abundant; thus, the microbial activity increased gradually, and the litter decomposed rapidly with increasing temperature. In May and June, the temperature continued to rise, and reproduction and activity of soil animals and soil microorganisms further accelerate the litter decomposition, increasing the quantity of litter loss. In July and August, although the higher temperatures are more favorable for microbial activity, the soil moisture was relatively high due to the increase in seasonal rainfall; thus, the soil was overly wet or anaerobic, inhibiting activities in the soil. In September, the temperature was relatively high, the soil moisture decreased to the level suitable for microbial survival at the end of the rainy season, the microbial activity was further activated, and the litter decomposition reached a peak. From May to October, the temperature was relatively high and basically suitable for soil activities. At this time, the main factor



**Fig. 5** Relationships between the quality loss of *Quercus acutissima* (*QAC*) and *Pinus densiflora* (*PSD*) litter and mean annual temperature (*MAT*) and precipitation (*MAP*) during the 300-day decomposition

affecting the litter decomposition was precipitation. From November to April of the following year, the soil moisture was relatively sufficient, but the temperature was relatively low, which greatly reduced soil activities. At this time, the dominant factor affecting litter decomposition was thus temperature.

**Effects of litter C, N, and P and their ecological stoichiometries on decomposition of *QAC* and *PSD* litter**

As essential elements for plant growth, C, N, and P are as important as water, light, temperature, humidity and other factors for plant growth and development (Yuan and Han 2009; Li et al. 2013). Throughout the 300 days of decomposition, the C contents of *QAC* and *PSD* litter were both 18.13% higher than the global value (Table 3) (Kang et al. 2010), indicating that the C content in litter was relatively rich in the study area. The N contents were 21.38% and 43.39% lower than the global value,

respectively. The P contents in the *QAC* and *PSD* litter were 24.71% and 10.38% higher, respectively, than the global value ( $0.85 \text{ g kg}^{-1}$ ) (Li et al. 2011). In this study, the N contents in the *QAC* and *PSD* litter were positively correlated with the decomposition rate (Table 5). The litter

**Table 5** Correlation between litter C, N and P contents and their ecological stoichiometries and litter quality loss rate (*D*) in *Quercus acutissima* (*QAC*) and *Pinus densiflora* (*PSD*)

Elements	Mean <i>D</i> (%)	
	<i>QAC</i>	<i>PSD</i>
C	- 0.304	- 0.426
N	0.776*	0.862**
P	0.865**	0.572
C:N	- 0.894**	- 0.888**
C:P	- 0.817**	- 0.623
N:P	- 0.580	- 0.379

Values are the means of 2 years (2016–2017). \*\* Significant at  $p < 0.01$ , \* Significant at  $p < 0.05$



decomposition rate is positively correlated with the litter N content early in litter decomposition (Song et al. 2018), when litter N is necessary for the growth and development of decomposers. Therefore, the litter nutrient contents will affect the litter decomposition by affecting the activities of decomposers, so when the initial nitrogen content is higher, the activities of microorganisms are relatively high, and litter decomposition is fast. In the late stage, with a decrease in the litter N content, there is a relative accumulation of refractory substances, microbial activity and thus decomposition decrease (Parton et al. 2007).

In our study, the C:N of the *QAC* litter was 2.93% higher than the global value, and the C:P of the litter was 33% lower than value (Bai et al. 1999). The C:N and C:P of the *PSD* litter were 4.41% and 48.61% lower, respectively, than the global value (Bai et al. 1999), the N:P of *QAC* and *PSD* litter were 53.98% and 63.61% lower, respectively (Table 3). Some studies have shown that when the litter C:N is lower than 40, mineralized decomposition and the net release of N begin to occur in the litter, and the lower the C:N and C:P, the faster the decomposition rate (Pan et al. 2011; Jing et al. 2017). In our study, the C:N of *QAC* and *PSD* litter was negatively correlated with the litter decomposition rate, which was higher than 40, indicating that the decomposition and mineralization of the litter was weak and the release of N was relatively slow, whereas the release rate of N in the *QAC* litter was higher than that in the *PSD* litter. Figures 3 and 4 show that the C:N of *QAC* and *PSD* litter were not related to the litter C contents during decomposition, but they were related to the accumulation and release of litter N; therefore, litter N was the key factor regulating the change in the C:N during decomposition of *QAC* and *PSD* litter. Some studies have shown that the higher C:N and N:P in the litter, the stronger the demands and binding capacities of nutrients, and the weaker the potential of nutrient release (Ouyang et al. 2013; Wei et al. 2018). Lower C:N and N:P make the litter easily decomposed. The C:N was lower, and litter decomposition was quicker, so turnover of ground litter layer was faster (Ouyang et al. 2013; Ma et al. 2014). The C:N can be used to determine decomposition rate and this is very important for studying nutrient cycling. In our study, the C:N of *QAC* and *PSD* litter were higher, which indicated that the nutrient release abilities of *QAC* and *PSD* were relatively weak, and thus decomposition was slow. Mixed forests can increase the productivity and stability of forests. Such forests can make full use of light energy and soil water and soil nutrients, and thus grow faster. In addition, mixed forests provide a wide variety of woods and other forest products, the structure of the aboveground and belowground parts are more complex than simple forests, and the protective effects are stronger. The more abundant litter and more complex components in mixed

forests also improve soil fertility better than in a simple forest (Zhang et al. 2015b; Ding et al. 2016). Therefore, during the selection of plantation species, attention should be paid to selecting nitrogen-fixing species and strengthening the construction of a mixed forest (e.g., *Robinia pseudoacacia* L., *Amorpha fruticosa* L. And *Hippophae rhamnoides* Linn.) during the restoration of vegetation in the GTGP area of the Taiyi Mountain area.

## Conclusion

Throughout the 300 days, the litter decomposition dynamics of *QAC* and *PSD* were slow-fast-slow. From May to October, precipitation was the main factor affecting the litter decomposition, and temperature was the primary influence from November to April of the following year.

Litter N content and the litter decomposition rate were positively correlated; the litter N was the key factor that regulated the change in the C:N during litter decomposition.

The C:N of *PSD* litter was higher than that of *QAC* litter ( $p < 0.05$ ), but the N:P of *QAC* litter was higher than that of *PSD* litter ( $p < 0.05$ ); the C:P was not significantly different between the two litter types. The C:N was negatively correlated with the decomposition rate of *QAC* and *PSD* litter.

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