Matter and Nutrient Dynamics of Pine (*Pinus tabulaeformis*) and Oak (*Quercus variabilis*) Litter in North China

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In the mountainous area of North China, a distinguishing feature of climate is the serious drought of spring and the humidity and high temperature of summer by which the litter production and decomposition of forest litter were strongly characterized. We investigated the dynamic and nutrient characteristics of litter in a 30-year-old mixed stand of Chinese pine (*Pinus tabulaeformis* Carr.) and deciduous orient oak (*Quercus variabilis* Bl.) and two comparable pure stands. Oak litterfall peaked in November and pine litterfall in December. The oak stand had the largest annual litterfall (347 $g\,m^{-2}$) and the forest floor mass (950 $g\,m^{-2}$), the mixed stand the second (236 $g\,m^{-2}$ and 634 $g\,m^{-2}$), and the pine stand the least (217 $g\,m^{-2}$ and 615 $g\,m^{-2}$). The nutrient return through litterfall and the storage in forest floor followed corresponding order between three stands. The weight loss of pine and oak foliage litter in first year was 25% and 20%. For senesced pine and oak leaves, the translocation rates of N, P and K were 56–83%. Nutrient concentrations were higher in oak leaf litter than pine needle litter, and the concentration of N and Ca appeared to rise while K concentration decreased in both decomposing litter.

Keywords decomposition, fall, forest floor, litter, nutrients, North China, *Pinus*, *Quercus*
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1 Introduction

The fall, decomposition and chemistry of litter are three important aspects for understanding the role of litter in nutrient cycling in a tree stand (Rodin and Bazilievich 1967, Attiwill and Adams 1993). Annual litter fall and the concentrations of nutrients in litter determine the amount of returned nutrients per year, and the decomposition rate of litter controls the speed at which bound nutrients are transferred into available form ready for reuse by plant uptake. Furthermore, the chemical composition of litter can influence the decomposition process, e.g. the litter of higher nitrogen concentration break down faster as it provides food of higher quality for decomposing organisms (Heal 1967, Anderson and Swift 1983, Johansson 1995b).

At a large geophysical scale, the patterns of litter fall and decay are controlled by climate factors, and in a given climatic condition a great difference exists between different types of forests (Bray and Gorham 1964, Meentemeyer 1986, Berg et al.1993). It is also reported that the chemical composition of litter varies with tree species, site conditions, climatic factors etc. (Rodin and Bazilievich 1967, Berg et al. 1994, Johansson 1995a). In addition, the nutrient concentrations of litter are always in dynamic process. Some nutrients and compounds are withdrawn from senescing plant tissues, and others show relative increase (Helmisaari 1992); the concentrations of some elements can increase while the others will decrease in decomposing litter (Berg and Cortina 1985).

The mountainous region of North China is one of most important water conservation and timber plantation regions in China. Historically, this area was densely forested with Chinese pine (*Pinus tabulaeformis* Carr.), deciduous oriental oak (*Quercus variabilis* Bl.), and Chinese arborvitae (*Platycladus orientalis*) as dominant species. However, about seven hundred years ago, the Yuan dynasty established the capital in present Beijing site, and since then human destructive activities degraded this area into treeless mountains covered only with some drought-resistant shrubs and grasses. Since the 1950s large-scale plantations have been established in order both to conserve water and soil and to produce timber. The pure and mixed stands of Chinese pine and oriental oak are most common (Wang 1983).

In this area, a distinguishing climatic feature is a serious drought in spring (from April to early June) and high humidity and temperature during summer (from late June to end of August). This climatic pattern has a strong effect on ecological and physiological processes in forests, e.g. growth rhythm of trees, and production of organic matter (Wang 1983, Liu 1987, Liu 1991a and 1991b). The aim of this paper is to determine the temporal patterns of litter fall and decay and the variation of nutrient elements in falling and decomposing litter in pure and mixed stands of Chinese pine and oriental oak in the North China mountain climate conditions. Also the storage of nutrients in the forest floor and the return through litter fall will be discussed.

2 Methods

2.1 Experimental Stands

The study area was located in Xishan, Beijing (39°57´ N, 116°19´ E). The area belongs to the warm temperate climate zone and has a continental monsoon climate. Average (1950–1980) annual temperature is 11.8 °C, annual precipitation 630 mm, and annual potential evaporation 799 mm. From April to June, the monthly poten-

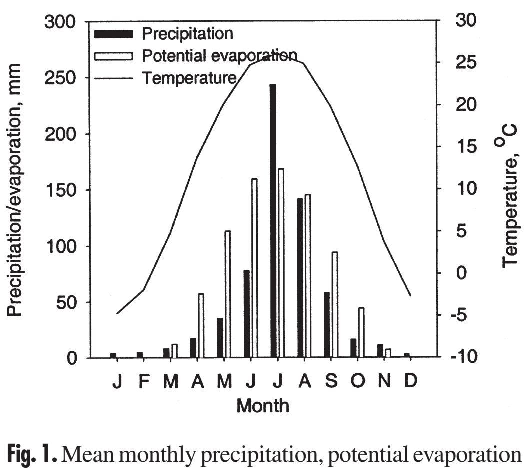

Fig. 1. Mean monthly precipitation, potential evaporation and temperature in the study area (1950–1980).

Table 1. Species composition, age, height, diameter at 1.3 m height (DBH) and density of three experimental stands.

Stand	Species	Age (yr.)	Mean height (m)	DBH (cm)	Density (trees ha^{-1})
Pine stand	*P. tabulaeformis*	28	5.2	8.1	2367
Mixed stand	*P. tabulaeformis*	28	5.5	7.4	1735
	Q. variabilis	27	6.9	8.2	759
Oak stand	*Q. variabilis*	27	7.6	8.0	1880

tial evaporation is more than double the precipitation, resulting in the total potential water deficit of 200 mm during the three months. Seventy-five per cent of the annual precipitation falls during July and August (Fig. 1). The main soil type is the leached brown soil developed on weathered sandstone. The original vegetation is typical to the North China flora, and dominant tree species are *P. tabulaeformis, Quercus* spp. and *Platycladus orientalis* L (Hou 1960).

The investigated pine stands were established by planting 2 year-old seedlings, and the oak stands by sowing. The initial spacing was 1.5 m × 2 m. In the pine-oak mixed stand, the pattern for the species mix was basically three by one rows with pine and oak. For this investigation, two pure stands, one oak and one pine, and one mixed stand were selected on the basis of three criterions. The sites were 200–250 m above sea level, had a south-east facing slope of 10–18°, and at least 90 cm in soil depth. In 1984, the stand age was 28 years for pine and 27 years for oak both in pure and mixed stands. The stands were undisturbed by other human activities except for a slight thinning. In each of the three stands one 30 m × 30 m plot was laid out. The tree characteristics of the experimental plots are listed in Table 1.

2.2 Annual Litter Fall and the Forest Floor Mass

The litter falling from trees was collected with litter collectors (1 m × 1 m × 0.3 m) from May 1984 to April 1985. In the pine and oak sample plots, 6 collectors were placed out systematically. In the mixed stand the number of collectors was 14. The litter was gathered once a month, and put in paper bags. In the laboratory, litter was separated into foliage, twigs, and cones of pine and acorn of oak.

In order to calculate the nutrient withdrawal from senescing foliage, foliage litter of oak and pine was collected in Nov. and Dec. 1985, and the living leaves and needles were collected from the middle positions of three pine and oak sample trees, respectively, in Aug.. The sampled needles were three years old, and the oak leaves were mature ones.

For the forest floor mass determination, 10 squares (1 m × 1 m) in the pure stands and 20 in the mixed stand were systematically delimited, and all litter of litter layer (L) and fermentation layer (F) within the area was raked up, and put into paper bags. In the laboratory, L layer litter was sorted according to the following categories, pine needle, pine twig, cone, oak leaf, oak twig, acorn and others. All the material of the F layer was classified as semi-decomposed matter. The dry weight was determined after the samples were oven-dried at 80 °C for 20 h.

2.3 Weight Loss of Foliage Litter

The decomposition rate of foliage litter during April 1984 to August 1985 was investigated using litterbags (size 10 cm × 10 cm, mesh size 1 mm). In each pure stand, 75 bags, each containing 5 g fresh foliage litter from either the pine stand or the oak stand, were placed under freshly fallen litter in five places (15 bags in each place). In the mixed stand, 75 bags, of which each contained a mixed sample of 5 g pine needles and 5 g oak leaves collected from the mixed stand, were placed out as in the pure stands.

Five bags in each stand were collected at intervals of 4 months. In the laboratory, the mixed samples of foliage litter from the mixed stand were separated into pine needle and oak leaf. The dry mass was obtained after the samples were dried at temperature of 85 °C for 20 hours.

2.4 Chemical Analysis

Nitrogen was determined by Kjeldahl digestion and distillation, phosphorus by colorimetry, potassium by flame photometry, and calcium and magnesium by the atomic absorption method. Sample preparation and detailed measurement procedures were carried out as described by Allen et al. (1976).

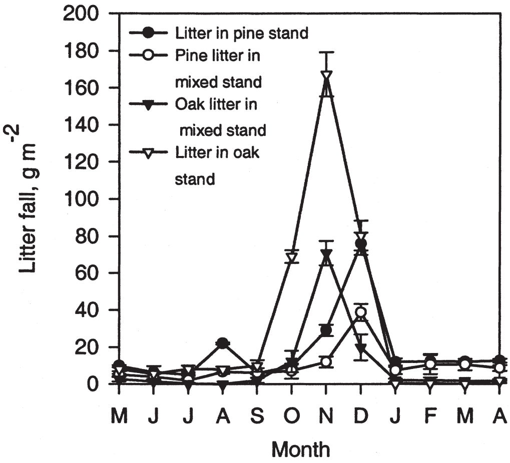

Fig. 2. Monthly variations of litter fall during the period of May 1984 to April 1985. Vertical bars are 1SD, n = 6 for the pine and oak stands, and n = 14 for the mixed stand.

3 Results

3.1 Annual Litter Fall and Nutrient Return

In the pine stand, litter fall peaked in December with a maximum of 76 $g\,m^{-2}\,month^{-1}$. In the oak stand, a corresponding peak (167 $g\,m^{-2}\,month^{-1}$) appeared in November. In the mixed stand, the litter fall pattern was two-peaked. Oak litter fell from October to November (71 $g\,m^{-2}\,month^{-1}$) and pine litter from November to December (39 $g\,m^{-2}\,month^{-1}$) (Fig. 2).

In senescing pine and oak leaves, more than half of nitrogen, phosphorus and potassium was re-located into other parts of trees in three stands while the concentrations of calcium and magnesium remained relatively unchanged (Table 2). The nutrient concentrations were generally higher in the oak litter leaves than the pine litter needles, and the concentrations were also higher in the litter which fell in the growing season than in other seasons (Fig. 3).

The amount of annual litter fall was the highest in the oak stand (347 $g\,m^{-2}\,yr^{-1}$), approximately one third less in the mixed stand (236 $g\,m^{-2}\,yr^{-1}$), and still somewhat smaller in the pine stand (217 $g\,m^{-2}\,yr^{-1}$) (Fig. 4). For all three stands, the proportion of leaves/needles was more than 90% of total aboveground litterfall. The annual return of various nutrients followed the same order of annual litterfall for three stands (Table 3).

Table 2. Retranslocation rates* of nutrients for senesced pine and oak leaves in three stands (%).

Nutrient elements	Needle in the pine stand	Needle in the mixed stand	Leaf in the mixed stand	Leaf in the the oak stand
N	61	56	60	69
P	71	81	79	83
K	70	70	57	70
Ca	3	–19	–17	11
Mg	13	–16	4	4

* Retranslocation rate (%) =

$$\frac{N_1 - N_2}{N_1} \times 100$$

where N_1 is nutrient concentration of living mature leaf, N_2 nutrient concentration of litter leaf.

3.2 Decomposition of Leaf Litter and the Change in Nutrient Concentrations

The litter decomposition took place mainly during the period from April 20th to August 20th

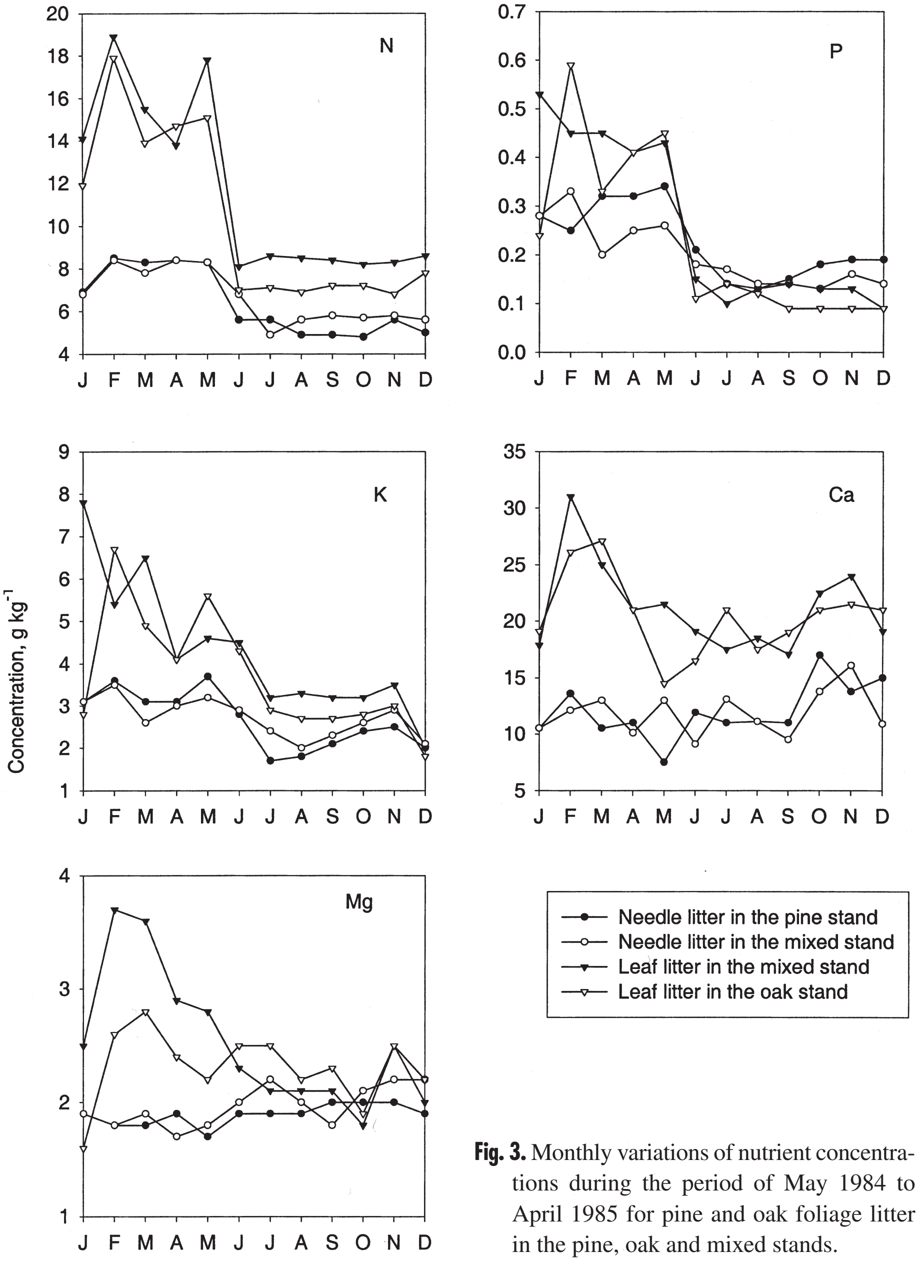

Fig. 3. Monthly variations of nutrient concentrations during the period of May 1984 to April 1985 for pine and oak foliage litter in the pine, oak and mixed stands.

Table 3. The annual return amount of nutrient elements through litter fall in three stands ($g\,m^{-2} \pm 1SD$, n = 6 in the pine and oak stands each, n = 14 in the mixed stand).

	N	P	K	Ca	Mg
Pine stand	1.06(±0.09)	0.031(±0.001)	0.42(±0.04)	2.35(±0.34)	0.39(±0.02)
Mixed stand	1.58(±0.11)	0.036(±0.002)	0.70(±0.08)	3.66(±0.17)	0.49(±0.04)
Oak stand	2.39(±0.11)	0.040(±0.001)	1.09(±0.01)	6.52(±0.79)	0.84(±0.07)

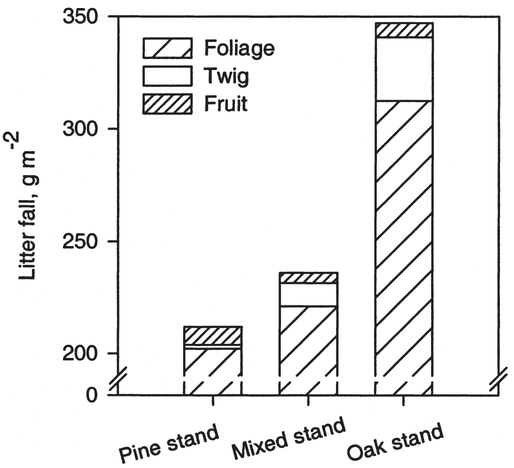

Fig. 4. Annual litterfall from May 1984 to April 1985 in the three stands. For the litterfall in the mixed stand, pine needle, twig and cone were 48%, 27% and 20% of the foliage, twig and fruit, respectively.

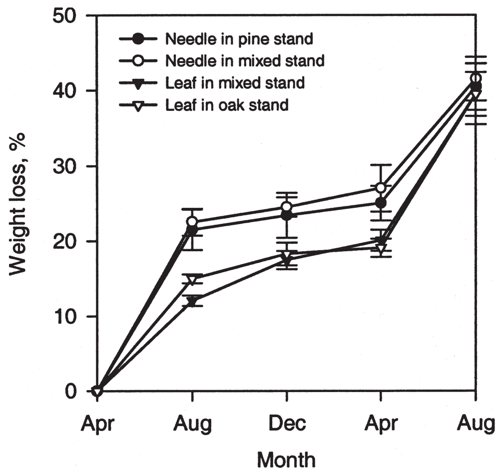

Fig. 5. Weight loss of pine needle litter and oak leaf litter during the period of April 1984 to August 1985 in the pine, mixed and oak stands. Vertical bars are 1SD , and n = 5.

Table 4. Nutrient contents of forest floor ($g\,m^{-2} \pm 1SD$) in the pine (n = 10), mixed (n = 20) and oak (n = 10) stands.

Plot	N	P	K	Ca	Mg
Pine stand	3.98(±0.35)	0.126(±0.097)	1.48(±0.13)	8.69(±0.57)	1.40(±0.11)
Mixed stand	4.80(±0.47)	0.135(±0.081)	1.89(±0.23)	9.91(±0.87)	1.41(±0.16)
Oak stand	9.35(±0.85)	0.184(±0.064)	2.57(±0.26)	23.38(±2.43)	2.03(±0.19)

while litter mass remained almost stable from September to next April. After 12 months, weight loss of pine needles was 25% and 27%, oak leaves 20% and 19% in the pure stands and mixed stand, respectively. At the end of second summer (after decomposition of 16 months), weight loss of needle and leaf litter was almost equal in all three stands, about 40% (Fig. 5).

In decomposing foliage litter, N and Ca concentrations appeared to rise, and K decreased sharply during the first four months when a fast breakdown happened; for other months (from September to April), weight-loss of litter was very small, and these three element concentrations remained almost constant (Fig. 5, Fig. 6).

3.3 Forest Floor Mass and Nutrient Content

The forest floor (L and F layers) mass was highest in the oak stand, about 950 $g\,m^{-2}$. In the mixed and in the pine stand the amounts were 634 $g\,m^{-2}$ and 615 $g\,m^{-2}$. The proportion of F layer mass was similar for all tree stands, ranging from about 33% to 40%. The proportion of needle or leaf material in L-layer was more than 50% and twigs about 8–10% both in the pine and mixed stands; leaf 37% and twig about 20% in the oak stand. For the mixed stand, the proportions of pine needle and twig, oak leaf and twig, and semi-decomposed matter averaged about one-third each (Fig. 7).

Table 4 showed that the nutrient contents of the forest floor in the three stands were similar

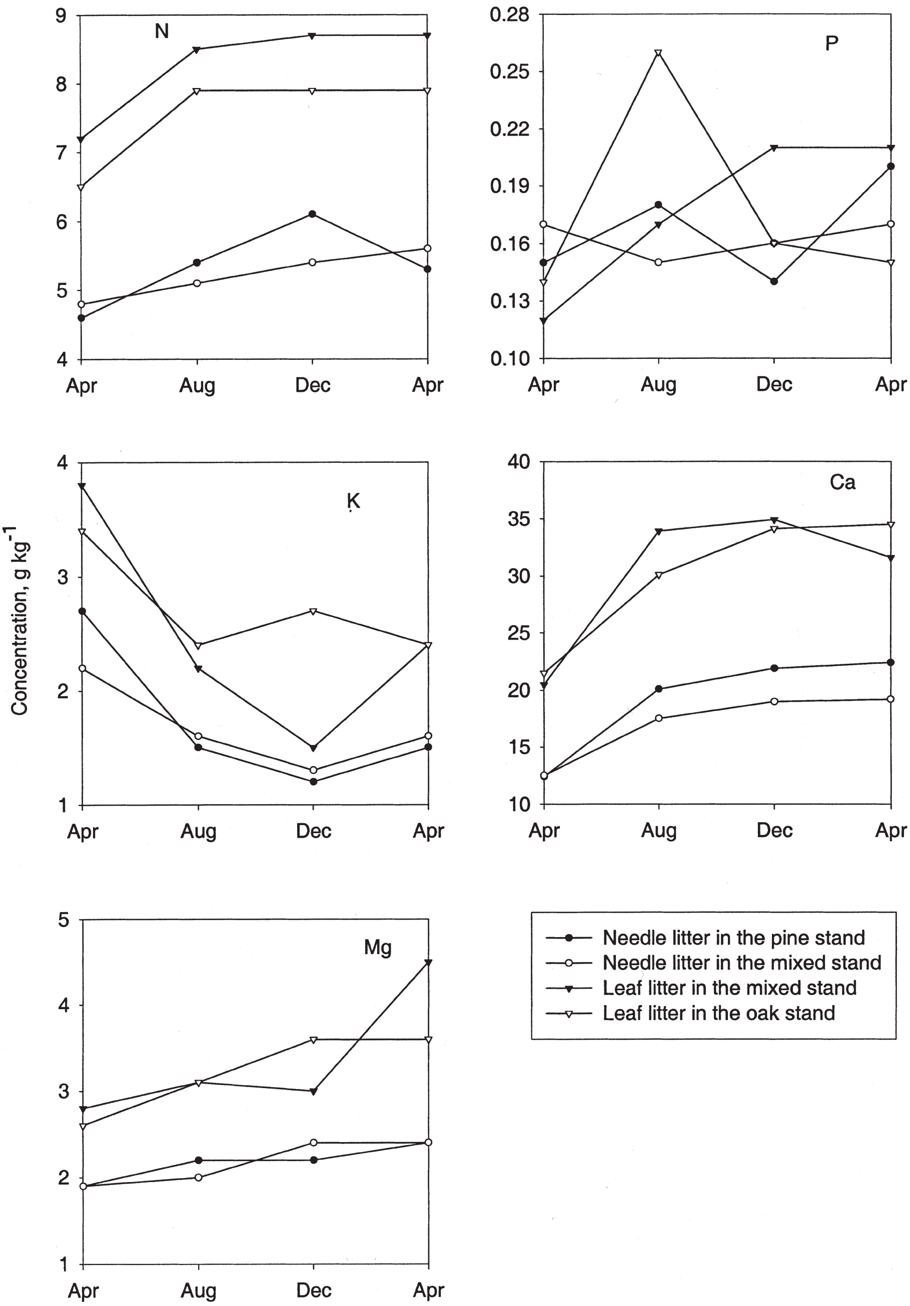

Fig. 6. Variations of nutrient concentrations in decomposing foliage litter during the period of April 1984 to April 1985. The values in April 1984 were initial nutrient concentrations of foliage litter.

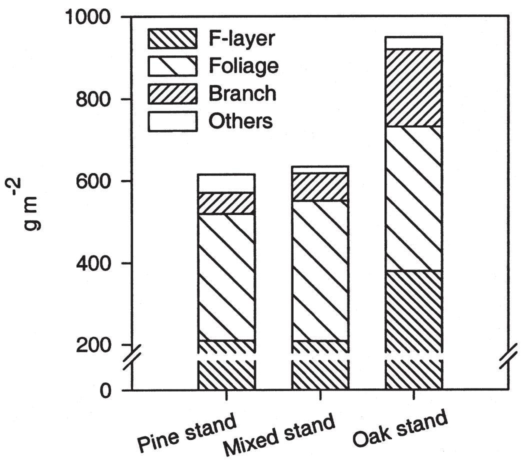

Fig. 7. The forest floor (L + F layers) mass accumulated in three stands. F-layer was semi-decomposed matter. The foliage, branch and others belonged to L layer.

to the rank of its mass. Among five nutrients, calcium had the biggest amount, and phosphorus the smallest.

4 Discussion

4.1 Pattern in Annual Litter Fall

Pinus and *Quercus* are two pan-continental genera in the Eurasia. In the warm-temperate climate region of China Chinese pine and oriental oak are the two most important species of the both genera. Annual litter fall pattern of oriental oak was similar to the observation in a sub-tropical oriental oak stand (Yu et al. 1994). *Quercus mongolia* in the Northeast China has a small litter peak in July and main one in September–October (Wang et al. 1991), and *Q. petraea* and *Q. robur* in Scotland have multiple-peaks from June to December (Tavakol and Proctor 1994). The litter fall pattern of Chinese pine differs from that of *Pinus sylvestris* which peaks in August in England and in September in Germany (see Bray 1964). In the Mediterranean area, litter fall of pine peaked in summer (Garcia-Plé et al. 1995, Hernandez et al.1992). These reflect the diversity of litter fall patterns, which likely vary with species and are modified by local climate conditions.

4.2 The Production and Decomposition of Litter and the Influencing Factors

In the temperate climate of Europe, annual litter fall for some *Pinus* forests is 158–348 $g\,m^{-2}$ (Miller et al. 1976, Breymeyer 1991), and 361–671 $g\,m^{-2}$ for *Quercus* forests (Drift 1974, Jakucs 1985, Tavakol and Proctor 1994). Compared with these data, the pine and oak litter fall found in the present study was lower, for which the arid spring and early summer climate was the decisive factor. In the actual climate region of North China, the frost-free period (about 190 days) begins in April, but from April to June the potential evaporation is double the actual precipitation (Fig. 1). Consequently, in the upper soil layers (0–30 cm), the water content is often below the content at soil wilting point and, this serious seasonal drought reduces the growth period to almost half of the frost-free period, and nearly stops tree growth until the middle of June (Liu 1991a, 1991b). In addition, the soils in the region are thin and nutrient-poor as a result of long-term erosion. With such climatic and site conditions, net primary productivity (NPP) was only about 500–800 $g\,m^{-2}\,yr^{-1}$ (Liu 1987), and an annual litter fall 200–300 $g\,m^{-2}\,yr^{-1}$ in the plantations.

In this study, the weight loss of pine and oak leaf litter in the first year was about 25% and 20% which is closely consistent with other investigations in this region (Nie 1985, Hu et al. 1986). In temperate climate regions in Europe, the weight loss of pine needle in the first year is reported to be 35–61 per cent (Dziadowiec 1987, Breymeyer 1991, Kratz 1991), and oak leaf 39 per cent (Dziadowiec 1987). In the study area, the soil moisture was too low for micro-organism decomposition activity in the spring and early summer (from April to June) while it became colder after September in the autumn. Only during the period of July to early September were both rainfall and temperature adequate (Fig. 1), and micro-organism activity strong enough to enable a fast loss in litter mass.

Generally fresh litter decomposes fastest, and the older the litter, the lower the decay rate. In the three stands, annual mean decomposition rate for all components of litter could not exceed the 25% (the first year weight-loss of fresh foliage litter); on the other hand, the ratios of annual litter fall to forest floor (L+F) mass were almost the same (0.35–0.37). These two numbers indicated that annual addition of litter was about 10% more than the annual loss of litter in the three stands, and the forest floor mass was increasing at this stage.

4.3 The Concentrations of Nutrient Elements in Foliage Litter

The concentrations of nutrients in foliage litter varied within the year. The most distinct difference existed between the foliage litter from the growing season and the foliage litter from periods when the litter fall-peaked (Fig. 3). This is mainly because the former was mainly damaged-young tissue, and the later was naturally senesced needle and leaf tissue from which part of the nutrients had been withdrawn prior to abscission. However the litter produced during the litter fall-peak period had greater contribution to nutrient return because of its higher total amount.

Compared with the investigation by Yu (1994), the oak leaf litter of the fall-peak period in this study had similar N (5.2–7.8 $g\,kg^{-1}$), K (2.8–3.2 $g\,kg^{-1}$) and Mg (2.3 $g\,kg^{-1}$) concentrations, smaller P (0.08–0.13 $g\,kg^{-1}$) concentration, and higher Ca (15.7–19.8 $g\,kg^{-1}$) concentration. For the pine needle litter of the fall-peak period, the concentrations of N (4.4–5.4 $g\,kg^{-1}$), P (0.17–0.14 $g\,kg^{-1}$) and K (2.1–2.4 $g\,kg^{-1}$) were smaller while Ca (11.8–11.9 $g\,kg^{-1}$) and Mg (2.0 $g\,kg^{-1}$) higher than those of Chinese pine litter in more humid region (Nie 1985). Generally, the litter of broad-leaved trees has higher nutrient concentrations than coniferous (Rodin and Bazilievich 1967), but the concentrations of only N, K and Ca were higher in oak leaf litter than in pine needles during the litter fall-peak period in this study (Fig. 3).

The retranslocation of nutrients from the senescing tissues is one of the factors influencing the nutrient concentrations of litter (Helmisaari 1992, Johansson 1995a). In this study, P had the highest retranslocation rate (71–83%), K the second highest (57–70%), and N the third highest (56–69%) for pine and oak foliage litter (Table 2). This might partly explain that in this study, P concentration of foliage litter was much lower than other investigations (Nie 1985, Yu 1994).

4.4 Implications for the Plantation Management in This Area

In the study area, serious spring-drought and barren soil are two limit factors to tree growth and stand productivity, and it is one of the most important issues how to reduce their pernicious effects with silvicultural measurements in plantation management. Our study showed that compered with the pine stand, the oak stand was much higher both in litter production and in the standing crop of forest floor, and the concentrations of nutrients are also higher in oak leaf litter than in pine needle litter. Generally, the higher the litter production, the more the nutrient return and the soil organic matter to be formed. The thicker forest floor can not only hold more rainwater itself, but also benefit rainwater to permeate the deeper soils as to reduce surface runoff (Liu 1991a). Thus, in such a mountainous area of barren soils and with yearly-600 mm-precipitation concentrating in June and August, establishing oak plantations has a better role in water and soil conservation and soil improvement than conifers, e.g. pine. In addition, the study stands are located in suburban area of Beijing city, and maintaining a beautiful landscape, e.g. evergreens' colour, is also an important consideration in forest management. In this context, planting mixed stands of pine and oak can be one good choice for both maintaining ecological benefit and aesthetic effect.

Acknowledgments

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