

# The influence of black locust (*Robinia pseudoacacia*) flower and leaf fall on soil phosphate

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**Abstract** To investigate the influence of black locust (*Robinia pseudoacacia*) flower and leaf fall on soil phosphate, we monitored litterfall, litter decomposition, and soil membrane phosphate in a *R. pseudoacacia* forest on Mt. Ilzasan, Seoul, Korea. *R. pseudoacacia* flower litter was 30–50% of total litter production in May and the flowers decomposed rapidly. More than 11% of *R. pseudoacacia* leaf litter decomposed from February to May, while that of *Quercus* spp. decomposed very little. Fast decomposition of *R. pseudoacacia* flower and leaf litter significantly increased membrane phosphate in the soil. The rapid nutrient-cycling of *R. pseudoacacia* through flower litterfall and rapid decomposition benefits the plant itself in the growing season when nutrients demand is increasing. Rapid nutrient-cycling might be a strategy that helps *R. pseudoacacia* to persist in poor soil environments.

**Keywords** Anion exchange resin membrane · Decomposition · Litterfall · Membrane phosphate · Nutrient-cycling · *Robinia pseudoacacia*

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## Introduction

Litter production in forest ecosystems varies with community type, tree density, tree age, and nutrient conditions, and is known to be affected by soil, temperature, precipitation, light, pests, and other environmental factors (Barbour et al. 1998). In general, when the forest reaches equilibrium, annual litter production is maintained at a constant level (Turner and Lambert 1986), but varies seasonally (Mitchell et al. 1986, Sharma and Ambasht 1987). More than half of annual net productivity is deposited as litter in forests (Barbour et al. 1998). Inflow and outflow of nutrients in forest is important for nutrient cycling and litterfall is clearly dominant among the aboveground components of net primary production (Bray and Gorham 1964, Kim and Chang 1989).

Litter decomposition is influenced by various environmental factors such as climate, soil, topography, decomposers, season, etc. (Chang et al. 1987). Most litters are biologically decomposed by soil microbes and bottom dwellers and litter decomposition rates vary with the physiochemical properties of soil and the climate, which affect the kinds and numbers of soil microbes and bottom dwellers (Swift et al. 1979, Yavitt and Fahey 1986). Precipitation is the most important environmental factor affecting litter decomposition (Fogel and Cromack 1977), and the chemical composition of the litter, especially the lignin:N, C:N, C:P, N:P ratios, also has important effects on its decomposition rate (Barbour et al. 1998,

Day 1983, Furniss and Ferrar 1982). Litter chemical composition varies with plant species, season, and organ.

Litter is the food source for decomposers on the ground and decomposed nutrients are returned to the cycling pool (Lee and Son 2006). Litterfall and litter decomposition represent a major contribution to the carbon and nutrient inputs in a forest ecosystem (Kim et al. 2003, Lee et al. 2006), and are the basic processes that sustains forest ecosystems because litter supplies most important nutrients for plant growth (Berg and Agren 1984).

*Robinia pseudoacacia* is deciduous, flowers in spring and bears a heavy crop of pea flowers. This plant was introduced into Korea in the 1890's, originally for use as railroad ties. In the 1950's and 1970's, *R. pseudoacacia* was planted in low mountain areas to restore forests and to supply fuel (Han and Gong 2003) because this plant symbiotically fixes N, grows rapidly (Boring and Swank 1984a) and can survive well in infertile soils. Also, this plant is important in honey production in Korea.

Nitrogen and phosphorus are most frequently the limiting nutrients in infertile soil (Salisbury and Ross 1992). *R. pseudoacacia* can overcome the N-limited environments by living in symbiosis with the N-fixing bacteria in its root nodules (Boring and Swank 1984b). On the other hand, the phosphorus content of soluble form in low-pH forest soil is very low because phosphorus combines with ferrous or aluminum at low pH and turns into insoluble form (Furihata et al. 1992). Soil pH is generally low in *R. pseudoacacia* forests. Therefore, N fixing *R. pseudoacacia* might have a higher P demand than non-fixers, and can mine the soil P pool. This suggests that phosphorus might be the most important element limiting the growth of *R. pseudoacacia*.

Phosphorus can be added to the soil via a few processes: dust input, pollen shed, and litter fall. The effects of pollen and litter on the nutrient budget are probably usually larger than that of dust. Pollen is intensively sheds for a period early in summer, and rapid cycling of pollen's nutrients plays an important role in supplying nutrients to the forest floor and promoting litter decomposition (Lee 1997). Most litter is produced in autumn and decomposes in summer in Korea (Kim and Chang 1989). Therefore, pollen can

add phosphorus in the early growing season and litter in the mid-growing season.

Most research on nutrient cycling in forest ecosystems has focused on annual litter production and decomposition, while few studies have examined seasonal variation in nutrient cycling or the effects of non-leafy materials on soil nutrients (Facelli and Pickett 1991).

The purpose of this study is to investigate the effects of litterfall, flower and leaf falls, of *R. pseudoacacia* on nutrient cycling in the early growing season, focusing on phosphorus. Specific objectives are 1) to determine seasonal litter production using litter traps, 2) to determine the decomposing rate using litter bags, and 3) to monitor the phosphate in soil using anion exchange resin membranes. To confirm the effect of *R. pseudoacacia* litterfall on nutrient cycling, data were compared with those in *Quercus* communities.

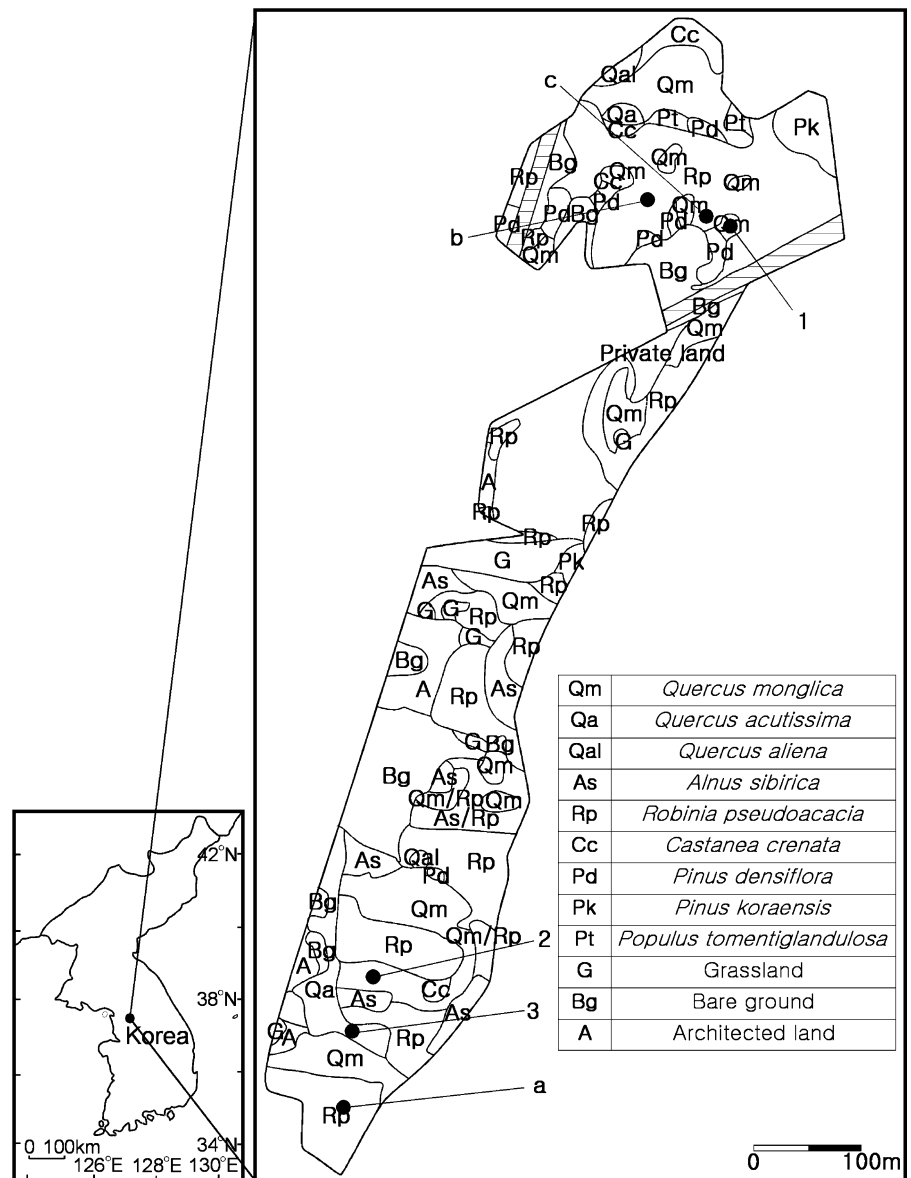
## Method

### Study area

This study was conducted at Mt. Ilzasan (37°31'27"N, 127°09'05"E, 110 m a.s.l.) in Seoul, Korea (Fig. 1). Annual mean temperature of Seoul is 12.2°C, and annual precipitation is 1344.3 mm. About 60% of annual precipitation is concentrated in July and August.

*R. pseudoacacia* communities are distributed on the north slope of Mt. Ilzasan and *Quercus* communities are found on the south slope. We selected three sites of size 20×20 m in *R. pseudoacacia* communities and three in *Quercus* communities. The three *R. pseudoacacia* community sites had different importance values (I.V. = relative density+relative coverage, Curtis and McIntosh 1951) for *R. pseudoacacia*: 163.7 at Site a, 105.2 at Site b and 84.3 at Site c (Table 1). Site b contained one *R. pseudoacacia* individual >40 cm DBH and Site c contained five, while Site a only contained five individuals with DBH <10 cm. This indicates that dominance of *R. pseudoacacia* was highest in Site a, intermediate in Site b and lowest in Site c. The dominant species in the *Quercus* communities were *Q. mongolica* in Site 1 and Site 2 and *Q. acutissima* in Site 3. The importance values of the dominant species in *Quercus*

**Fig. 1** Location of the study area in Korea (a, b, c: *R. pseudoacacia* community research sites, 1, 2, 3: *Quercus* community research sites)



communities were 88.1 in Site 1, 76.4 in Site 2 and 169.5 in Site 3 (Table 1).

### Measuring litter production

Two 1 × 1 m litter traps were placed under the middle of dominant species trees in each site on December 17, 2008. Litterfall was collected at monthly intervals until November 2009 except in the winter and in the flowering season. Litterfall was collected on March 26, 2009 for the winter and on a weekly basis from

May 13 to June 18, which spanned the flower-shedding event. All samples were sorted into flowers, leaves, and other plant organs, and dried at 80°C for 48 h. Each fraction was weighed separately for each litter trap with an accuracy of 0.01 g (Scout Pro SPG202F, Ohaus Corporation, China).

Analysis of inorganic nutrients in flower fall and leaf fall of *R. pseudoacacia*

Flowers and leaves of *R. pseudoacacia* were collected immediately after they fell in spring or autumn. Litter

**Table 1** The importance values of trees in *R. pseudoacacia* communities and *Quercus* communities (RD: Relative Density, RC: Relative Coverage, IV: Importance Value)

Species	<i>R. pseudoacacia</i> community						<i>Quercus</i> community									
	Site a		Site b		Site c		Site 1		Site 2		Site 3					
	R.D.	R.C.	I.V.	R.D.	R.C.	I.V.	R.D.	R.C.	I.V.	R.D.	R.C.	I.V.				
<i>Robinia pseudoacacia</i>	71.4	92.2	163.7	24.2	80.9	105.2	19.4	64.9	84.3							
<i>Quercus mongolica</i>	11.4	1.8	13.2				40.6	47.4	88.1	22.7	53.6	76.4				
<i>Quercus dentata</i>	8.6	1.1	9.7				15.6	26.8	42.4							
<i>Quercus serrata</i>	2.9	4.6	7.4													
<i>Castanea crenata</i>	5.7	0.3	6.0	8.1	7.3	15.4	8.1	7.5	15.6							
<i>Quercus aliena</i>				63.6	10.1	73.7	51.6	21.7	73.3	9.4	9.2	18.6				
<i>Quercus acutissima</i>				2.0	0.4	2.4	6.5	5.2	11.7	9.4	10.3	19.7			74.3	95.2
<i>Cornus controversa</i>				1.0	0.7	1.7										
<i>Prunus serrulata</i> var. <i>pubescens</i>				1.0	0.6	1.6										
<i>Corylus heterophylla</i> var. <i>thunbergii</i>							12.9	0.6	13.5	6.3	0.1	6.4			6.8	3.1
<i>Syrax japonica</i>							1.6	0.0	1.6						9.9	25.7
<i>Sorbus alnifolia</i>													56.8	23.4	80.2	
<i>Betula davurica</i>													13.6	19.9	33.6	

was dried at 80°C for 48 h immediately after collection. We milled the dried litter with a WILLY MINI-MILL (3380 L10, Thomas, USA) and then filtered it with 40-mesh (0.425 mm). Total nitrogen (T-N) was determined using an Elemental Analyzer (Flash EA 1112, Thermo Electron, USA) and total phosphorus (T-P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were measured using a Inductively Coupled Plasma Emission Spectrometer (ICPS-1000IV, Shimadzu, Japan) after nitric acid digestion (Havlin and Soltanpour 1980) at the National Instrumentation Center for Environmental Management (NICEM) in Seoul National University.

### Litter decomposition

The litter decomposition rate was measured using a litterbag method. Newly fallen leaf litter from two tree taxa (*R. pseudoacacia* and *Quercus* spp.) was collected on the forest floor on 25 November 2008. We filled 1-mm mesh nylon litterbags (20×20 cm) with 8.0 g of air-dried *R. pseudoacacia* leaf litter or 10.0 g of air-dried *Quercus* spp. leaf litter. Litterbags containing *R. pseudoacacia* leaf litter were placed in *R. pseudoacacia* community sites, and litterbags containing *Quercus* spp. litter were placed in both *R. pseudoacacia* and *Quercus* community sites on 17 February 2009. Four litterbags of each taxon were retrieved from each site at 100-day intervals. We used the decomposition model of Olson (1963) to calculate the annual decay constant (k) using the below equation.

$$W_t = e^{-kt}W_0$$

( $W_0$ : weight at time zero,  $W_t$ : weight at time t (in years))

### Membrane phosphate

Membrane phosphate was assessed using anion exchange resin (AER) strips (VWR ID No: 5516400, VWR International Ltd. Leics, England). The AER sheets were cut into 50×20 mm strips. The AER strips were converted into 75% bicarbonate form and 25% chloride form (Sibbesen 1978). A thin vertical slot was made in the soil A layer using a small steel bar of similar dimensions to the strip. The

AER strip was placed into the slot without disturbing the soil any further (Bowatte et al. 2008). Twelve strips were installed at each site and the strips were replaced every 7 or 8 days from May 19 to October 15, 2009. Recovered strips were transferred in 50 mL polypropylene tubes containing 10 mL of phosphate reagent including ammonium paramolybdate, potassium antimony tartarate, sulphuric acid, and ascorbic acid (Saggar et al. 1990) and 40 mL of deionized water and the solution in the tubes was stirred several times over the course of 30 min until the blue color was fully developed. The concentration of phosphate was determined by the absorbance of the solution at a wavelength of 712 nm on a spectrophotometer.

Data analyses

SPSS for windows (version 15.0) was used for statistical analysis. To compare differences among sites, one way ANOVA and Duncan post hoc test were performed. Repeated measures ANOVA was conducted to compare data (membrane phosphate and litter decomposition) measured at several times. Litter decomposition in the repeated measures ANOVA used the ratio of the total weight remaining after 100, 200, 300 days.

Results

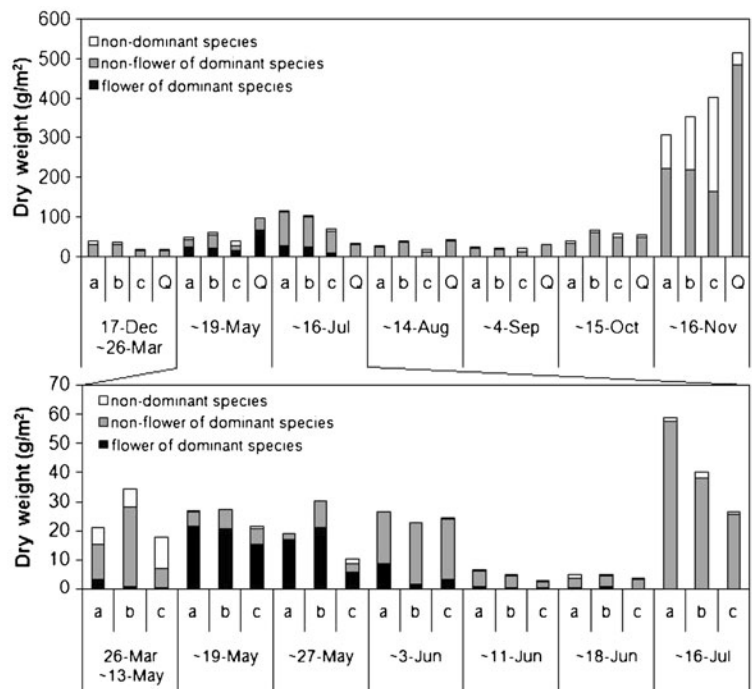
Production of litter

Litter production of *R. pseudoacacia* communities and *Quercus* communities showed two peaks, one in spring and one in autumn (Fig. 2). There was no statistical difference in the amount of annual litter production among the plant communities, but the flower production in *R. pseudoacacia* communities was significantly different among the communities. Flower fall account for considerable portion of the spring peak, while the autumn peak was mainly due to leaf fall.

The community structure at Site a differed from those at Site b and c (Table 1). The dominance of *R. pseudoacacia* was overwhelming at Site a but trees of *Quercus* spp., especially *Q. aliena*, had equal dominance to *R. pseudoacacia* at Site b and c. Therefore, the proportion of *R. pseudoacacia* in the litter was greater at Site a than at Site b and c.

*R. pseudoacacia* flower fall first appeared on May 13th, peaked on May 18th and 27th, and then declined drastically at Site b and c but remained high at Site a on June 3rd (Fig. 2). The proportion of flower fall from *R. pseudoacacia* in the total litter averaged 49.11% at Site a, 36.58% at Site b, and 30.81% at Site c from May to late June. In the *Quercus* communities, the

**Fig. 2** Litter production in *R. pseudoacacia* communities and *Quercus* communities. a, b, c: *R. pseudoacacia* communities, Q: *Quercus* communities



average proportion (70.50%) of flower litter in the total litter from May to late June was larger than in the *R. pseudoacacia* community because fruits of *R. pseudoacacia* fall in spring, and leaflets fall little by little in spring and summer, but acorns and leaves of *Quercus* spp. rarely fall in spring.

Inorganic nutrients in flower fall and leaf fall of *R. pseudoacacia*

The concentrations of total nitrogen and phosphorus were significantly different between the flowers and the leaves of *R. pseudoacacia* (Table 2). The flowers of *R. pseudoacacia* had 4.04% of T-N, or twice as high as the concentration in leaves, and T-P concentration in flowers was about five times higher than in leaves. However, Ca and Na were lower in flowers than in leaves. That is, the flowers of *R. pseudoacacia* are rich in nitrogen and phosphorus.

#### Decomposition of leaf litter

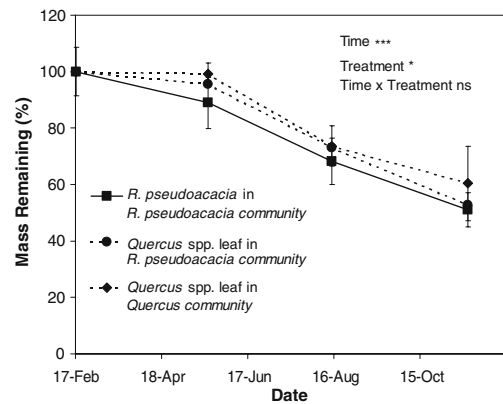
The decay constant (k) of *R. pseudoacacia* leaf litter in *R. pseudoacacia* communities was 1.213 and the k-values of *Quercus* spp. leaf litter in *R. pseudoacacia* communities and in *Quercus* communities were 1.191 and 1.043, respectively.

*R. pseudoacacia* leaf litter lost 11.15% of its mass from 17 February to 20 May in *R. pseudoacacia* communities, and *Quercus* spp. leaf litters lost 4.44% and 0.91% of their masses in *R. pseudoacacia* and *Quercus* communities, respectively (Fig. 3). Repeated measures ANOVA showed that there was a highly

**Table 2** Inorganic nutrients in fallen *R. pseudoacacia* flowers and leaves (T-N: total nitrogen, T-P: total phosphorus, Average  $\pm$  1 SD,  $n=4$ )

	Flower	Leaf
T-N (mg/g)*	40.44 $\pm$ 10.88	19.92 $\pm$ 2.76
T-P (mg/g)*	3.30 $\pm$ 0.21	0.63 $\pm$ 0.09
K (mg/g)	17.49 $\pm$ 0.86	10.97 $\pm$ 3.32
Ca (mg/g)*	2.30 $\pm$ 1.20	19.72 $\pm$ 0.73
Mg (mg/g)*	0.95 $\pm$ 0.27	0.80 $\pm$ 0.17
Na (mg/g)*	0.05 $\pm$ 0.01	0.29 $\pm$ 0.05

\*indicates significant difference between two groups based on t-test,  $p<0.05$



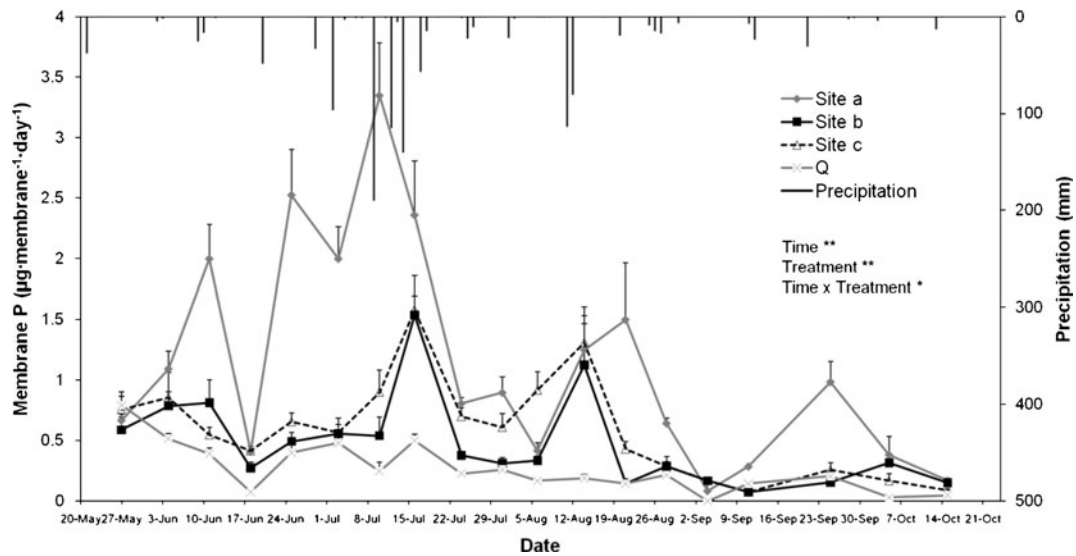
**Fig. 3** Percentage of remaining dry mass during a nine-month litterbag study. The interval between recovered dates was about 90 days. Bar indicates 1 Standard Error ( $n=4$ ). Significance of main effects of treatment and time are noted as \*\*\* $p<0.001$ ; \* $p<0.05$ ; ns not significant

significant main-effect of date ( $F_{2, 50}=145.3$ ,  $p<0.0001$ ) and the mass loss was significantly different among the communities ( $F_{2,25}=3.9$ ,  $p=0.034$ ). The decomposition of *R. pseudoacacia* litter started earlier than that of *Quercus* spp. litter and the mass loss rate of *R. pseudoacacia* leaf litter from May to August was faster than that of *Quercus* spp. leaf litter. *Quercus* spp. leaf litter decomposed faster in *R. pseudoacacia* communities than in *Quercus* communities.

#### Membrane phosphate in soil

Mauchly's test of sphericity was highly significant ( $p<0.0001$ ), and therepeated measures ANOVA with Huynh-Feldt correction was used. The factor 'Sampling date' had significant difference ( $F_{55.7, 4.6}=3.9$ ,  $p=0.005$ ) and there were significant interactions between sampling date and sites ( $F_{55.7,13.9}=2.0$ ,  $p=0.032$ ). Membrane phosphate in soil was significantly different among the sites ( $F_{3,12}=7.5$ ,  $p=0.004$ ), and post hoc tests showed that membrane phosphate in the soil was significantly higher in *R. pseudoacacia* communities than in *Quercus* communities during most of the study period ( $p<0.05$ ). Among the study sites, the membrane phosphate was highest in Site A (Fig. 4), which had the highest relative density and coverage of *R. pseudoacacia* (Table 1).

The pattern of change in membrane phosphate in the soil was similar to that of precipitation (Fig. 4). From 11 June to 18 June, there was no precipitation and membrane phosphate was very low in all communities. Except for this week, however, mem-



**Fig. 4** Changes in membrane phosphate in soil and precipitation. (Site a, Site b, Site c: *R. pseudoacacia* communities, Q: *Quercus* communities). Bar at data points of phosphorus

indicates 1 Standard Error ( $n=12$ ). Significance of main effects of treatment and time are noted as \*\* $p<0.01$ ; \* $p<0.05$

brane phosphate in *R. pseudoacacia* communities increased (Site a) or remained steady (Site b and c) from May to June in *R. pseudoacacia* communities, but not in *Quercus* communities.

## Discussion

The difference of the phenology according to plant species can affect the production of litter fall. The litter fall during the growing period is noticeable from an aspect of nutrient cycling although most of litter fall happen in autumn. Thus, the early litterfall of *R. pseudoacacia* during the period from mid-May to mid-June have a potential as nutrient sources during the rapid growing season when nutritional demands are increasing. In particular, the amount of flower fall in *R. pseudoacacia* communities exceeded the leaf fall during the flowering season. In addition, the flowers are more nutritional than the leaves in that nutrients necessary for plant growth, such as N, P, and K, are more abundant in the flowers.

Rim (1981) reported that most flowers are not only rich in P and N, but the decomposition rate is also generally high. The flowers of *R. pseudoacacia* fell on the forest floor intensively from 13 to 27 May and were not observed any more with naked eye on the forest floor since 11 June. This fact suggests that the

flowers of *R. pseudoacacia* were assumed to be decomposed within 2 weeks. Therefore, highly nutritious flowers of *R. pseudoacacia* can support the plant growth through rapid decomposition, suggesting that rapid nutrient cycling might occur in *R. pseudoacacia* communities in the growing season.

The nutrients in the rapidly decomposed leaves can be used as nutrient sources by vigorous plants. Thus, the extent of the leaf decomposition can be important in nutrient cycling. The decomposition of the leaf litter was highest in the period from May to August within this study period. Previous studies also reported that the decomposition in litter bags increased in the summer (Kim 2003, Yang and Shim 2003), and especially from July to August, when the precipitation in Korea is high (Kim and Chang 1989). White et al. (1988) reported that *R. pseudoacacia* leaf litters decompose rapidly in a year and then decompose very slowly.

The leaf decomposition can also depend on the shape of leaves (Barbour et al. 1998). And compound leaves provide much greater edge surface area for attack by decomposers. Thus, being pinnately compound and soft, the leaves of *R. pseudoacacia* can be vulnerable to the decomposition. Although the decomposition rate can vary with the environmental characteristics of the study area (Tateno et al. 2007), the decomposition rate of *R. pseudoacacia* leaves in

this study using litter bag method was higher than the rate measured by using the annual production of the organic carbon in litters and the amount of the accumulated organic carbon on the forest floor in another study (Kim and Chang 1997). And the decomposition of *R. pseudoacacia* leaves in their own communities was faster than that of *Quercus* leaves in their own communities, indicating the rapid decomposition of *R. pseudoacacia* leaf in summer season.

In addition, *Quercus* spp. leaf litter decomposed faster in *R. pseudoacacia* communities than in *Quercus* communities. Mixed-species litter was reported to decompose faster than single-species litter (Gartner and Cardon 2004). Thus, we can suppose that the proliferation of decomposers in the *R. pseudoacacia* leaves being decomposed may also accelerate the decomposition of *Quercus* leaves in *R. pseudoacacia* communities. And the early decomposition of leaf litter in *R. pseudoacacia* communities during the growing season can also supply significant nutrition for the plant community.

The membrane phosphate in soil was relatively higher in *R. pseudoacacia* communities than in *Q. mongolica* communities, and in particular, the site where *R. pseudoacacia* were definitely dominant in the density and coverage had remarkably higher concentration of membrane phosphate (Fig. 4). Chang et al. (1987) also found that the amounts of phosphorus returned to soil annually in *R. pseudoacacia* forests are greater than those in *Q. mongolica* forests. Therefore, the increased adsorption of phosphate to the membranes in the soil can be caused by the rapid decomposition of leaves and flowers. In particular, the input of the phosphorus-abundant and rapidly-decomposable flowers may promote phosphorus cycling during the initial growing season, the period from the end of May to early in June (Figs. 2 and 4).

In addition to the decomposed litter fall, the precipitation also seemed to influence the increased adsorption of phosphate to the membranes in the soil in this study (Fig. 4). This can be explained by the change of phosphate mobility. That is, the increased precipitation can promote the movement of phosphate in soil and then, the adsorption of phosphate to the membranes in the soil can be raised. However, even after taking the effect of the precipitation into consideration, the increased adsorption of phosphate to the membranes in the soil was more distinguished in *R. pseudoacacia* communities. This suggests that

the mobility of phosphate in soil tend to be higher in *R. pseudoacacia* communities than in *Q. mongolica* communities. In conclusion, we can suggest that the litter fall of *R. pseudoacacia*, specifically the fallen flowers and their rapid decomposition support the rapid cycling of nutrient such as phosphorus in *R. pseudoacacia* communities.

**Synthesis** The proportion of *R. pseudoacacia* flower fall in the total litter was high in the period from May to late June. *R. pseudoacacia* flowers contain more phosphorus than leaves and rapid decomposition of *R. pseudoacacia* flowers increases the phosphorus availability in the soil in the early growing season when the nutrient demand is increasing. In addition, *R. pseudoacacia* leaf fall decomposes faster than *Quercus* spp. leaf fall and thus increase of dissolved phosphate by rapid decomposition of leaves causes more increase of phosphorus in *R. pseudoacacia* communities than in *Quercus* communities. Our results show that phosphorus circulates more rapidly in *R. pseudoacacia* communities than in *Quercus* communities. Rapid phosphorus cycling and uptake of nitrogen through symbiosis with legume bacteria help *R. pseudoacacia* to grow well in infertile soil.

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