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ORIGINAL PAPER

Comparison of litterfall production in three forest types in Jeju Island, South Korea

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Abstract Litterfall, which is influenced by physical and biological factors, is a major pathway for carbon and nutrient cycling in forest ecosystems. The purpose of this study was to investigate monthly litterfall production in three forests in Jeju Island differentiated by forest composition and precipitation: Cheongsu (*Quercus glauca* as the dominant species; low precipitation), Seonheul$_b$ (*Q. glauca* as the dominant species; high precipitation), and Seonheul$_m$ (*Q. glauca* and *Pinus thunbergii* as the dominant species; high precipitation). Litterfall was collected monthly from April to December 2015 and divided into leaf litter, twig, bark, seeds, and unidentified materials. Seasonal patterns of litterfall production varied across stands according to their species composition. However, the amount of leaf litterfall and total litterfall were comparable among stands, ranging from 362 to 375 g m^{-2} for leaf litter and 524 g m^{-2} to 580 g m^{-2} for total litterfall. Oak leaf litter in May was the highest in all stands, while needle litter was the highest in December in Seonheul$_m$. High twig litterfall in July may be attributable to high rainfall with strong winds and storms during the rainy season. Although forest type and climate factor had no influence on litterfall amounts in this study, the pattern of litterfall production was species dependent, suggesting diverse effects on carbon and nutrient cycling in these forests.

Keywords Coniferous forest · Evergreen broadleaved forest · Gotjawal · Leaf litter · Precipitation · Temperature

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Introduction

Forest ecosystems play an important role in global carbon cycling as atmospheric CO_2 and climate continuously change (Pan et al. 2011). A large part of the net primary productivity (NPP) of forests is directly or indirectly contributed by leaves that generally accumulate as litterfall on the forest floor. This litterfall is an important pathway of carbon and nutrient cycling in forest ecosystems (Bray and Gorham 1964; Berg and Laskowski 2005; Kim et al. 2005; Kang et al. 2010).

Litter acts as an input–output system for nutrients on the forest floor and maintains soil fertility in forest ecosystems through this nutrient cycling (Olson 1963; Singh et al. 1999; Fioretto et al. 2003; Onyekwelu et al. 2006; Pandey et al. 2007). However, it is not easy to determine the amount and pattern of litterfall in forest ecosystems (Zhou et al. 2007) because of the many influential factors (e.g., temperature, precipitation, site conditions, time, and forest types).

Litterfall production depends on species composition as well as forest type. Zhou et al. (2007) found the lowest litterfall in a pine forest at 356 g m^{-2} and the highest litterfall in a ravine rain forest at 1061 g m^{-2} along successional and altitudinal gradients of subtropical monsoon evergreen broadleaved forests in China in an 11-year study. They also reported that litterfall production was highest from April to September, the summer season. Bray and Gorham (1964) reported that evergreen coniferous forests produced higher leaf litter (by 8%) and total litterfall (by 17%) than deciduous broadleaves forests did. Similarly, An et al. (2017) studied five deciduous broadleaved forests and four evergreen coniferous forests at the Gwangneung Experimental Forest in South Korea and reported 556 g m^{-2} litterfall for coniferous forests, higher than the 436 g m^{-2} litterfall for deciduous forests. In India, Sundarapandian and Swamy (1999) also reported variation in the mean annual litterfall (ranging from 563 to 865 g m^{-2}) across sites attributable to species composition. However, Yanai et al. (2012) observed that litterfall varied considerably year to year rather than across 13 successional northern hardwood forests in USA.

Litterfall production is also influenced by climate factors in forests, but studies have shown diverse results. Litterfall production peaks in the dry season in a tropical forest in India (Sundarapandian and Swamy 1999). However, Guadalupe and Tolome (1996) reported that litterfall production is related to phytogeographic origin in a lower montane forest in Mexico: Holarctic species showed a strong negative correlation with precipitation and minimum temperatures, but tropical species showed a significant positive correlation with maximum temperature. Liu et al. (2004) determined the relationships between climatic factors and litterfall in Eurasian forests at a continental scale and found that a relative unit change in temperature (annual mean temperature change from − 8 to 30 °C) had more effect on litterfall than that in precipitation (annual mean precipitation change from 350 to 4000 mm). Kouki and Hokkanen (1992) studied needle litterfall in a Scots pine (*Pinus sylvestris* L.) stand in Finland for over 24 years and found that litterfall amount varied from year to year ranging from 18 to 213 g m^{-2} because of July temperature: a 1 °C increase in July temperature increased needle litterfall by 36 g m^{-2}.

Jeju Island, formed by four volcanic events, is located in the Korea Strait in the southernmost part of South Korea, and approximately 48% of the island is covered with forests, of which 34% are broadleaved forests (Korea Forest Service 2015). The Gotjawal Forest is one of the most important forest types in Jeju Island referring to a unique natural unmanaged forest with dense trees and understory shrub vegetation formed on widely and disorderly distributed lava blocks (Park 2010). Thus, this unique ecosystem makes highly diverse microclimate with severe topographic heterogeneity (Choi and Lee 2015). Recently, the Gotjawal Forest has received more attention because it plays an important role in the maintenance of ecosystem services (Jeon et al. 2012; Jeong 2012; Kang et al. 2013). However, relatively little is known about litterfall production and dynamics in this area.

The main purpose of our study was to investigate the monthly litterfall production in three forests in relation to climatic factors. We hypothesized that (1) litterfall production varies according to forest types and time, and (2) the pattern of seasonal litterfall production differs by forest types and climatic factors.

Materials and methods

Study sites and stand descriptions

The experiment was conducted in 2015 in three forest stands at two sites in Jeju Island, Republic of Korea: Cheongsu Gotjawal (33°18′14.79″N and 126°16′16.67″E, about 120 m a.s.l.) and Seonheul Gotjawal (33°30′38.82″N and 126°43′13.25″E, about 110 m a.s.l.). Cheongsu Gotjawal (hearafter, Cheongsu) is distributed on lava plateau in the western part of Jeju Island, having locally distributed water holes on gentle slopes. Seonheul Gotjawal (hearafter, Seonheul) is located in the northeastern part of the island characterized by small lava caves, wetlands and a parasitic volcano terrain (Jeon et al. 2012).

Monthly temperature and precipitation data were provided by the meteorological center near each study site: Seongsan Station (33°23′N and 126°53′E, 20 m a.s.l.), 17 km from Cheongsu; Gosan Station (33°18′N and 126°10′E, 71 m a.s.l.), 9 km from Seonheul. Mean annual temperature did not differ between Cheongsu (15.6 °C) and Seonheul (15.7 °C); however, annual precipitation was about 61% higher at Seonheul (2496 mm) than Cheongsu (1546 mm). The temperature was the highest in August and the lowest in January; the winter temperature was mostly above 5 °C for the three stands (Fig. 1). The precipitation was greatest in July for Seonheul and in May for Cheongsu and lowest in October for both sites (Fig. 2). Monthly precipitation was always 1.2–2.8 times higher at Seonheul than Cheongsu except in June.

The stand in Cheongsu is an evergreen broadleaf forest dominated by *Quercus glauca* with 5.3 m^2 ha^{-1} in mean basal area and 9.5 m in height (Table 1). Other canopy and subcanopy trees such as *Actinodaphne lancifolia*, *Ficus*

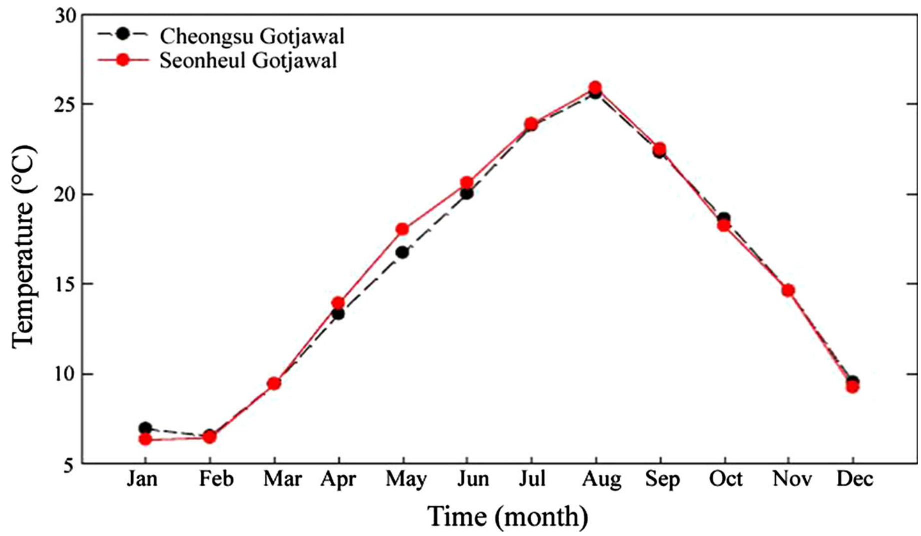

Fig. 1 Monthly change of temperature at Cheongsu Gotjawal and Seonheul Gotjawal in 2015

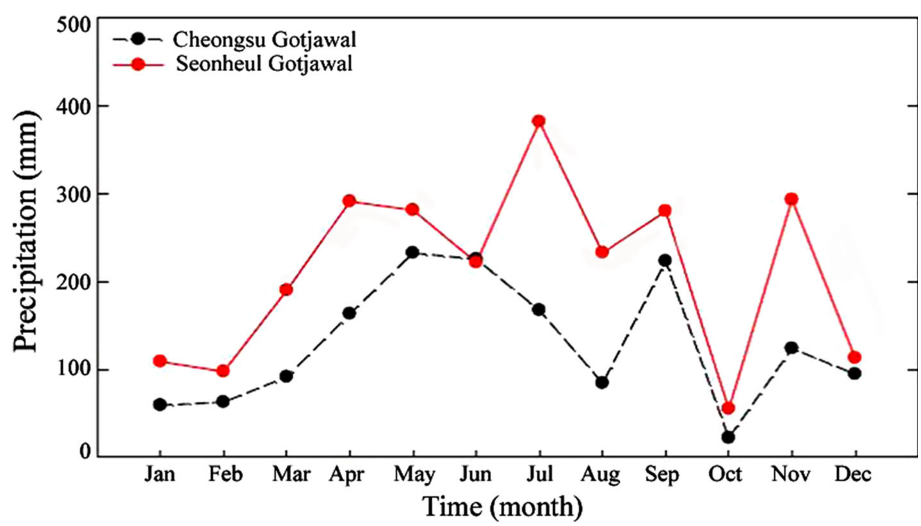

Fig. 2 Monthly precipitation at Cheongsu Gotjawal and Seonheul Gotjawal in 2015

Table 1 Mean basal area (m^2 ha^{-1}) in the three forest stands

Species	Cheongsu		Seonheul$_b$		Seonheul$_m$	
	m^2 ha^{-1}	%	m^2 ha^{-1}	%	m^2 ha^{-1}	%
Oaks	3.5	66	8.0	85	2.9	31
Pine	0.0	0	0.0	0	5.7	61
Other	1.8	34	1.4	15	0.8	8
Total	5.3	100	9.4	100	9.4	100

erecta, *Cinnamomum camphora*, *Cinnamomum yabunikkei*, *Celtis sinensis*, *Acer palmatum* and *Picrasma quassioides* account for 34% of total basal area. As mentioned, annual mean temperature was similar among the stands, but the annual precipitation was the lowest in Cheongsu (Figs. 1, 2). The stand in Seonheul is also an evergreen broadleaf forest dominated by *Q. glauca* with 12.5 m in tree height, but the mean basal area and precipitation are higher than those in Cheongsu (hereafter, Seonheul$_b$; Table 1, Fig. 2). Other canopy and subcanopy tree species such as *Quercus salicina*, *Prunus pendula*, and *Styrax japonica*, account for 15% of total basal area in Seonheul$_b$. The other stand in Seonheul Gotjawal is a mixed evergreen forest dominated by *Q. glauca* and *Pinus thunbergii* with mean basal area and precipitation similar to those in Seonheul$_b$ (hereafter, Seonheul$_m$; Table 1, Fig. 2). In Seonheul$_m$, canopy tree height was 10.8 m for *Q. glauca* and 13.1 m for *P. thunbergii*. Here, subcanopy species such as *Camellia japonica*, *Distylium racemosum*, and *Acer palmatum*, etc. accounted for 8% of total basal area, and tree height ranged from 3.0 to 6.4 m.

Litterfall collection

Litterfall was collected using a circular plastic litter trap 67 cm in diameter and installed 30 cm from the ground in March 2015. To minimize the loss of litter from the litter traps, we installed an iron mesh (mesh size: 2 mm) at the bottom of the litter trap. Rocks were placed in each trap to prevent overflow and loss of litter.

Each stand was divided into four plots with four litter traps in each plot. The distance between plots was at least 20 m, and the four litter traps within each plot were spaced 12 m apart in the shape of a quadrangle. Thus, 48 litter traps were installed for the three stands.

Litterfall was collected monthly from April to December 2015. The collected litter was dried immediately at room temperature to prevent decomposition. Air-dried litterfall was separated into leaves, twigs, bark, seeds, and unidentified materials. Particularly, leaf litter was further classified into evergreen oak (*Q. glauca*, *Q. gilva*, and *Q. saliciana*), *P. thunbergii*, and others. The separated samples were oven-dried at 65 °C for 48 h to a constant mass and then weighed. Annual litterfall production was estimated by summing the monthly litterfall mass during the study.

Statistical analyses

Two-way analysis of variance (ANOVA) was performed to detect the effects of stands and time on leaf litter, other litterfall, and total litterfall production. When there was no interaction, one-way ANOVA was performed to test for significant differences in litterfall production. Multiple comparisons of means were completed using Duncan's multiple range test at $\alpha = 0.05$. All statistical analyses were performed using SAS 9.4 software (SAS Institute, Cary, NC, USA).

Results

Annual litterfall variation by stand

Total litterfall was not significantly different across three forests (Table 2) and the value was 524 g m^{-2} in Cheongsu, 580 g m^{-2} in Seonheul$_b$, and 531 g m^{-2} in Seonheul$_m$. However, the composition of litterfall showed different patterns by stand (Figs. 3, 4). Leaf litterfall of all tree species accounted for 86% on average of total litterfall (Fig. 5). As expected by species composition in basal area (Table 1), oak leaf litter was higher in Cheongsu and Seonheul$_b$ than in Seonheul$_m$ ($p < 0.01$), and needle litter was much higher in Seonheul$_m$ than in Cheongsu and Seonheul$_b$ ($p < 0.01$). The litter of other leaves was higher in Cheongsu and Seonheul$_b$ than in Seonheul$_m$ by 3.8 times ($p < 0.01$). Twig litter was the highest in Seonheul$_b$ and seed litter was the lowest in Cheongsu. Even though leaf litter by species varied by stand, total leaf litter was similar among the stands ($p = 0.95$) ranging from 362 to 375 g m^{-2} (Fig. 5).

Monthly litterfall variation

Litterfall production varied across months from May to December (Figs. 3, 4). Oak leaf litter was the highest in May, which was 99 g m^{-2} in Cheongsu, 144 g m^{-2} in Seonheul$_b$, and 60 g m^{-2} in Seonheul$_m$, but it was very low during the other months, ranging from 9.3 to 14.7 g m^{-2}. On the other hand, needle litter in Seonheul$_m$ was the highest in December followed by November (Fig. 3). Although we did not classify flower litter separately, most of the unknown materials in May consisted of flower litter. There was a significant effect of season on twig and seed litter production (Table 2). Twig litter production was the highest in July, while seed litter production was higher in October and November than in other months in all stands. Unidentified materials were the highest in May.

Table 2 Results of two-way analysis of variance (ANOVA) for litterfall variation among stands and times. Bold numbers indicate statistically significant *p*-values (<0.05)

Litter components	Stand (2 df)	Time (7 df)	Stand × Time (14 df)
Leaf litterfall			
Oaks	**< 0.01**	**< 0.01**	**< 0.01**
Pine	**< 0.01**	**0.02**	**< 0.01**
Others	**< 0.01**	0.55	0.09
Other litterfall			
Twig	**< 0.01**	**< 0.01**	0.35
Seed	0.44	**< 0.01**	0.36
Bark	0.90	**0.03**	0.58
Unidentified materials	**< 0.01**	**< 0.01**	**< 0.01**
Leaf total	0.95	**< 0.01**	**< 0.01**
Total litterfall	0.12	**< 0.01**	0.10

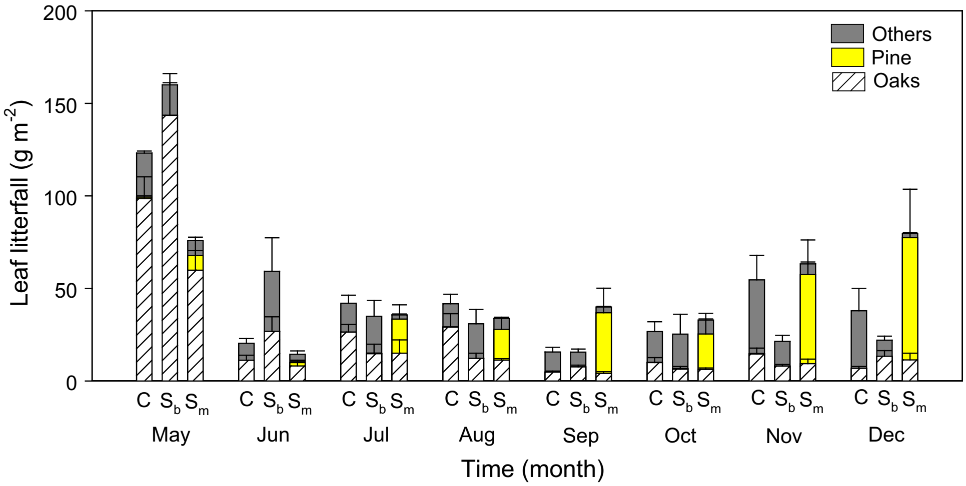

Fig. 3 Monthly variation in leaf litterfall mass. Oaks includes *Quercus glauca*, *Q. accutisima*, *Q. alinena* species, pine means *Pinus thunbergii*, and others include all leaf litters except oaks and pine. C, Cheongsu; S_b, Seonheul$_b$; S_m, Seonheul$_m$. Vertical bars show standard errors ($n = 4$)

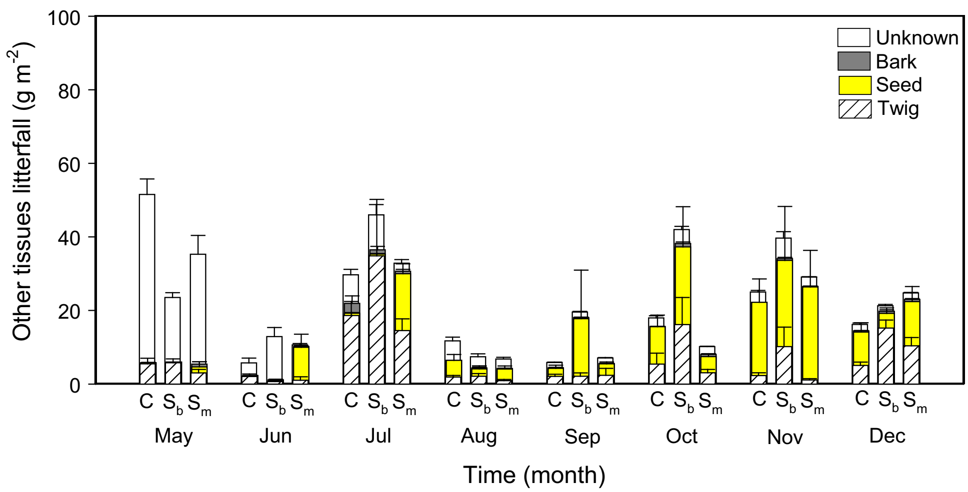

Fig. 4 Monthly variation in other litterfall mass. Unknown, unidentified materials; C, Cheongsu; S_b, Seonheul$_b$; S_m Seonheul$_m$. Vertical bars show standard errors ($n = 4$)

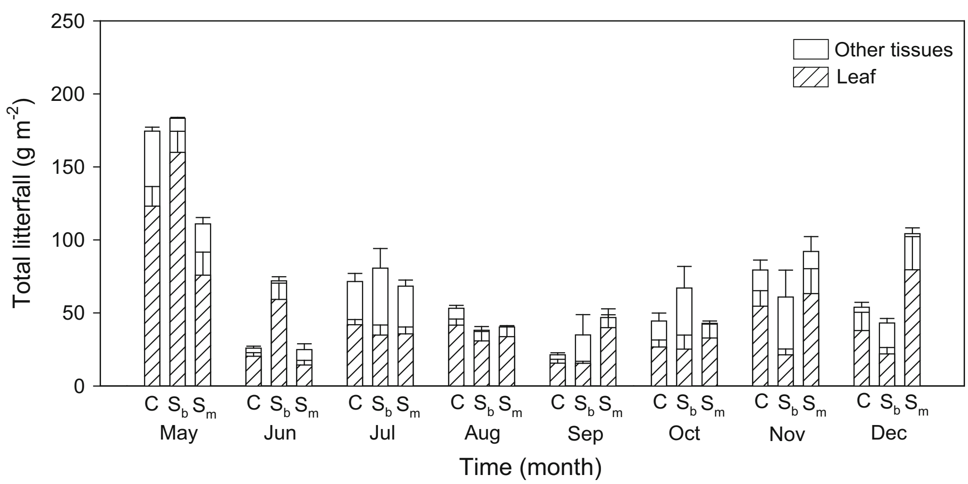

Fig. 5 Monthly variation in leaf litter and other tissues litterfall mass. Other tissues, the sum of twigs, bark, seeds and unidentified materials; C, Cheongsu; S_b, Seonheul$_b$; S_m Seonheul$_m$. Vertical bars show standard errors ($n = 4$)

The proportion of leaf litter in May was the highest, but the proportion varied significantly by stand: 33% in Cheongsu, 35% in Seonheul$_b$, and 21% in Seonheul$_m$. The proportion of leaf litter in December was 50% lower in Cheongsu and Seonheul$_b$ than in Seonheul$_m$ (Fig. 5).

Discussion

Leaf litter and total litterfall were comparable to those observed in the same subtropical forest zone in Korea from 2009 to 2012 (Jung 2015). The average leaf litter across three stands in this study was 369 g m^{-2}, which was somewhat lower than that for broadleaf forests, 424 g m^{-2} (from 84 to 910 g m^{-2}), but a little higher than that for needle leaf forests, 331 g m^{-2} (from 94 to 704 g m^{-2}) in Asian subtropical zones (Liu et al. 2004). The total litterfall was 545 g m^{-2} on average within the range of the reported values for broadleaf and needle leaf forests in Korea (An et al. 2017).

Leaf litter and total litterfall were similar among three different forests even though the basal area in Cheongsu was only 56% of that in $Seonheul_b$ and $Seonheul_m$. This result did not correspond with the results of other studies. For example, Starr et al. (2005) reported that both needle leaf litter and total leaf litter were significantly correlated with the basal area of Scots pine stands in Finland. Kunhamu et al. (2009) reported that basal area has a linear relationship with litterfall production in *Acacia mangium* stands subjected to various thinning intensities. However, litterfall mass differed according to the age and stand basal area of the forest in a northern hardwood forest in the United States; after a certain age (approximately 30 years), the amount of litterfall tended to be constant without a large increase (Yanai et al. 2006, 2012; Park et al. 2007). Comparable leaf litter and total litterfall among stands in this study may be attributed to canopy closure; that is, the crown was already closed in all three stands so that annual partitioning of carbon was greater to the bole or roots rather than to the leaves.

Liu et al. (2004) explored the litterfall data for broadleaf and coniferous forests in Eurasia to examine the relationship between climatic factors and litterfall. They found that the relationship between litterfall and climatic factors has significantly higher coefficients in broadleaf stands than in coniferous forests. They concluded that temperature change had a greater effect on litterfall than precipitation change did across the Eurasian forests. In contrast, we found no differences in leaf litter and total litterfall between Cheongsu and Seonheul forests even though the precipitation in Cheongsu was 40% lower than in $Seonheul_b$ and $Seonheul_m$ (Table 2, Fig. 2). It might be attributable to increased carbon allocation to the bole or coarse roots rather than to the leaf or fine root after crown closure as mentioned above. Another reason might be no water shortage in all stands: the annual precipitation of 1546 mm in Cheongsu during the study would provide enough water for tree growth in this area. One more possible explanation can be raised that precipitation or water availability is not a limiting factor for leaf production in all stands because trees adapted to rocky areas with high rainfall percolation.

In this study, the variation in litter production was more prominent for seasonal pattern. The timing of leaf fall varies depending on tree species, and this difference may be attributable to plant life histories or micro-environmental factors (Boojh and Ramakrishnan 1981; Sundriyal 1990; Kikim and Yadava 2001; Kikuzawa and Lechowicz 2011). As leaves get older, net primary production of trees declines because of decreased photosynthetic capacity and increased respiration cost in leaves (Reich 1995; Westoby et al. 2002; Kikuzawa 2003; Miyazawa and Kikuzawa 2004). Therefore, leaf shedding is cost effective to maintain the aged leaves and dry matter production. In the present study, total litterfall peaked in May for all stands, but the composition of litterfall varied between stands. The highest oak leaf litter was observed in May in all stands, and this pattern was comparable to a previous study in a similar climatic zone in northeast Spain, where evergreen oak leaf litter was the highest during May and June (Caritat et al. 2006). According to Ralhan et al. (1985), leaf drop for most evergreen broadleaved species is concentrated leaf drop in spring and summer, but leaves are not all shed until new leaves are fully expanded; old leaves of *Quercus* spp. start turning yellow and falling soon after appearing young shoots. Nitta and Ohsawa (1997) also reported peak leaf fall in May to June in a study of leaf dynamics in 11 warm-temperate evergreen broadleaved trees in Japan. In spring when the weather starts to warm, longer daylight time and increased soil water availability, the plants seem to prepare for the most favorable growth by replacing a majority of old leaves with new leaves early in the season, which in turn maximizes carbon gain (Ralhan et al. 1985; Devi and Garkoti 2013). On the other hand, in our study, pine needle litter peaked during fall and winter in November and December as found by Liu et al. (2001) who reported that pine litterfall peaked in December in North China. Also, needle litter production in *P. sylvestris* forests peaks in October in the northeastern region of the Iberian Peninsula (Pausas 1997), needle litterfall rate of *P. densiflora* is the highest between October and December in Japan (Miura 2000), and needle litterfall production reaches its maximum values between October and November in Korea (Kim et al. 2009). Compared with other studies on pine needle litterfall, we found slightly delayed needle litter production from late fall to winter, with the highest production in December. In the study area, monthly temperature decreased greatly from 14.6 °C in November to 9.3 °C in December, triggering high leaf drop (Bhat 1992). The oak trees, *Q. glauca* in this study, generally have a flowering peak in April, the average duration of flowering continues about 4 weeks; thereafter, flowers drop as litterfall (Ralhan et al. 1985). Likewise, we found a high proportion of flower litter in May in all stands although we included flower litter as unidentified materials. Seed production was much higher in November as a result of acorn production. The production of twig litter peaked in summer from the combined effects of rainfall, strong winds and storms (Caritat et al. 2006). Environmental factors such as strong winds and storms may have distinct effects on twig and branch litterfall (Christensen 1975; Park et al. 2008).

The different timing of litterfall production may affect the decomposition process on the forest floor. According to previous studies, the decomposition rate of oak leaf litter is much higher in summer due to high rainfall, air temperature, and relative humidity (Pandey et al. 2007). On the other hand, needle litter decomposition is much slower during winter because of low soil moisture and temperature (Tripathi and Singh 1992).

Conclusions

Litterfall production was similar among stands even though there were remarkable differences in basal area and annual precipitation between stands. However, the litterfall composition differed distinctly according to time and forest structure. The differences in average mean diameter at breast height after crown closure or climatic factors such as precipitation had no effect on the litterfall production. However, the genetic and ecological characteristics of tree species such as evergreen coniferous versus evergreen broadleaf species are considered to influence on the fluctuation in litterfall production. The difference in seasonal leaf and litterfall production among stands will also affect the decomposition process of litter, resulting in varying effects on carbon and nutrient cycling in these forests.

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