

Carbon and Nitrogen Responses of Litterfall Components by NPK and PK Fertilizers in a Red Pine (*Pinus densiflora* S. et Z.) Stand

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Abstract: This study was conducted to determine the carbon (C) and nitrogen (N) response of litterfall components as affected by N addition in compound fertilizer in a Korean red pine (*Pinus densiflora* S. et Z.) stand in southern Korea. Litterfall in a mature red pine stand was collected for two years following compound fertilizer application (N₃P₄K₁; P₄K₁) and no fertilization (control). The C concentration of litterfall components was not significantly ($P > 0.05$) different between the N₃P₄K₁ and the control plots, whereas the N concentration of the litterfall components was significantly higher in the N₃P₄K₁ plot than in the control plot. The N₃P₄K₁ and P₄K₁ additions induced a lower C/N ratio of litterfall components compared with the control plot. Annual C and N fluxes via litterfall components were not affected by the N₃P₄K₁ addition over the study period, except for reproduction litter. Annual N fluxes via reproduction litter were significantly higher in the N₃P₄K₁ plot than in the control plot. Thus, the N₃P₄K₁ and P₄K₁ additions could modify differently nutrient distribution of the forest floor and mineral soils in a red pine stand. These results indicate that N concentration and C/N ratio in litterfall components are more susceptible to fertilizer application than the C response in litterfall components.

Key words: carbon cycling; nitrogen cycling; fertilization; litterfall; nitrogen addition

Introduction

Nutrient returns via litterfall represent an important parameter for assessing nutrient cycling in forest stands (Berg and Laskowski, 2006). However, nutrient returns via litterfall on a small local scale depend on forest management activities, such as fertilization (Smaill et al., 2008; Kim et al., 2013a) and thinning (Kim et al., 2009). For example, fertilization can change the nutrient processes of litterfall because the nutrient concentration and content in litterfall can change with the shift in nutrient availability induced by fertilizer (Lee and Son, 2006; Kim et al., 2013b; Huang et al., 2016). However, previous fertilization studies related to the nutrient responses of litterfall have focused mainly on nitrogen (N) or phosphorus (P) fertilizer alone (Lee and Son, 2006; Mayor

et al., 2014; Huang et al., 2016), since N or P are commonly known to be limiting elements for forest productivity (Mayor et al., 2014; Sardans et al., 2017). Such studies found that foliar N and P concentrations increased by P fertilization because of increased N-uptake capacity due to enhanced P availability, whereas N fertilization led to increased N concentration in foliage (Sardans et al., 2017).

Despite the previous findings, the nutrient responses of litterfall to the combined application of N and P fertilizers are still unclear. They may be different with the response following N addition in compound fertilizer because the nutrient dynamics of litterfall could be affected by different soil nutrient availability induced by compound fertilizer types. In addition, it is necessary to investigate the effects of N or P fertilizer on the nutrient response of litterfall because nutrient deficiency commonly occurs in many forest stands (Weetman and Wells, 1990; Kim et al., 2014; Kim et al., 2015).

Korean red pine (*Pinus densiflora* S. et Z.) is the most dominant conifer tree distributed throughout the country

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(Kim et al., 2014). However, many studies have reported multi-nutrient deficiency problems in red pine stands through needle nutrient analysis (Joo et al., 1983; Kim et al., 2013b; Kim et al., 2014). Thus, compound fertilizer was recommended to increase annual tree growth in most Korean red pine forest stands (Kim et al., 2014). Although the nutrient dynamics in the litterfall may be a factor in determining the response to fertilizers (Smaill et al., 2008; Kim et al., 2013b; Baek et al., 2018), little is known about the behavior of nutrient dynamics of litterfall components following the additions of NPK and PK. Additionally, previous studies mainly focused on the nutrient dynamics of needle litter (Vose and Allen, 1991; Sariyildiz and Anderson, 2005; Yang et al., 2017), whereas they rarely involved the nutrient dynamics of litterfall components such as bark, branches, reproduction and miscellaneous litter as affected by fertilizer.

The objective of this study was to measure the C and N response of litterfall components following NPK and PK additions in a red pine stand. The hypothesis of this study was that the application of fertilizer would alter C and N dynamics in litterfall by improving soil nutrient availability. To address this hypothesis, two different types of fertilizers ($N_3P_4K_1$ and P_4K_1) were applied experimentally to a Korean red pine stand, which has been monitored for approximately two years.

Materials and Methods

The study site was located in a matured red pine stands (about 40 years old) with low forest productivity (site index, 8-10) in the Wola National Experimental Forest (35°12'32"N, 128°10'23"E, 180 m; 35°12'26"N; 128°10'25"E,

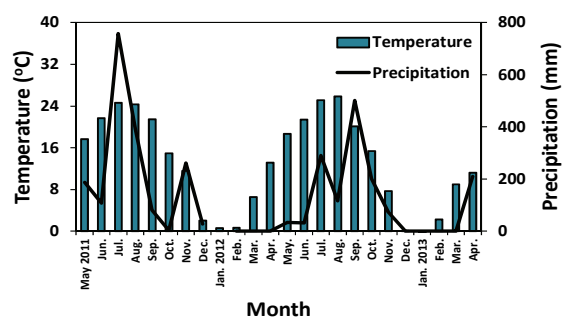


Figure 1. Monthly temperature and precipitation of the study site.

195 m), in Jinju, Korea. The annual average precipitation and temperature during two study years are 1,635 mm yr⁻¹ and 13.15 °C, respectively (Figure 1). The forest soil type is a slightly dry, dark-brown forest soil that corresponds to Inceptisols in USDA soil taxonomy. Total 18 plots [(three treatments (NPK, PK, Control) × two blocks × three replicated plots)] were established and each block was divided into nine 10 m × 10 m plots with a 5 m buffer zone. The applied fertilizer types (urea, fused superphosphate and potassium chloride fertilizers) included a compound fertilizer following the fertilization guideline ($N_3P_4K_1=113:150:37$ kg ha⁻¹) in Korea forests (Joo et al., 1983) and that without N component ($P_4K_1=150:37$ kg ha⁻¹) to determine N fertilizer effects in compound fertilizer. More information in the study site can be found in other studies (Kim et al., 2017; Baek et al., 2018).

Three circular litter traps (with a surface area of 0.25 m²) were installed at each treatment plot (for a total of 54 litter traps) to measure C and N fluxes via litterfall components. Litter was collected at monthly intervals and oven-dried at 65 °C for 48 hours in a laboratory. All dried samples were separated into litterfall components (needle,

Table 1. General stand and soil characteristics of the study site before fertilizer application.

Treatment	Stand density (trees·ha ⁻¹)	DBH (cm)	Basal area (m ² ·ha ⁻¹)	Soil pH	Organic C (%)	Total N (%)	Available P (mg·kg ⁻¹)	K ⁺ (cmolc·kg ⁻¹)
Control	1217 (133)	15.74 (0.84)	22.37 (1.95)	4.65 (0.06)	2.40 (0.28)	0.07 (0.01)	3.9 (0.40)	0.09 (0.01)
$N_3P_4K_1$	1150 (193)	15.89 (1.10)	20.56 (2.42)	4.85 (0.06)	2.82 (0.21)	0.09 (0.01)	6.5 (0.73)	0.09 (0.01)
P_4K_1	1150 (152)	16.46 (1.46)	22.62 (2.00)	4.73 (0.05)	2.66 (0.27)	0.08 (0.01)	5.8 (1.61)	0.09 (0.01)

Values in parenthesis represent standard errors ($n = 6$). DBH: diameter at breast height at 1.2 m.

bark, branches, reproduction and miscellaneous) and was weighed. The litterfall component samples collected for each sampling month between May 2011 and April 2013 were composited with three seasonal sampling times of heavy litterfall season (October-November), winter season (December-March) and two growing seasons (early growing season: April- June; late growing season: July-September). The composited litter samples were ground in a Wiley mill for C and N analysis. Carbon and N concentrations from the ground materials were determined using an elemental analyzer (Thermo Scientific, Flash 2000, Italy). Annual C and N fluxes via litterfall components were calculated by multiplying the litterfall weight by C and N concentrations of litterfall components. After KCl extracting of a 5-gram of fresh mineral soil by a mechanical vacuum extractor (Model 24VE, SampleTek, Science Hill, KY, USA), ammonium ($\text{NH}_4^+\text{-N}$) and nitrate ($\text{NO}_3^-\text{-N}$) concentrations from the soil solution following fertilization were determined using an auto analyzer (AQ2 Discrete Analyzer, UK).

Three-way analysis of variance (ANOVA) was used to determine the significance of main effects [fertilizer treatment (F), sampling month (M), litterfall components (C)] and their interactions ($F \times M$, $M \times C$, $F \times C$, $F \times M \times C$) at $P < 0.05$ by the GLM procedure in SAS (SAS Institute, 2003). All post-hoc analysis for mean separations was conducted with Tukey's test.

Results and Discussion

1. Carbon and nitrogen concentration of litterfall components

The N addition in compound fertilizer had a significant effect on the inorganic soil N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) con-

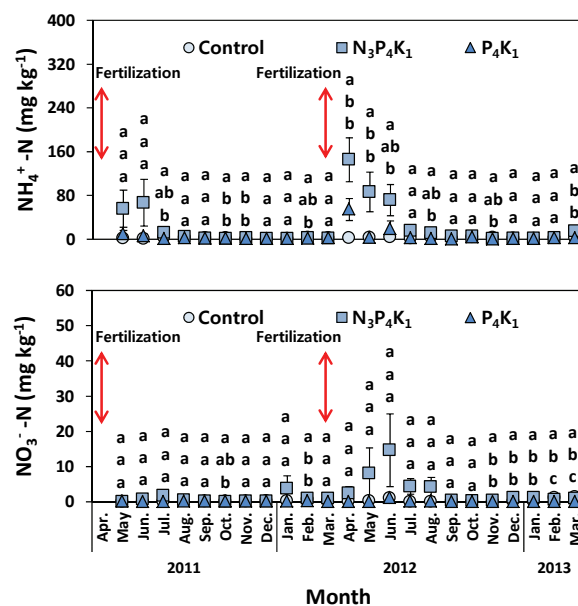


Figure 2. Monthly variation of soil $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ concentration ($n=6$) following fertilizer applications in a red pine stand. Vertical bars represent standard error. Different letters on the bars indicate significant difference between fertilizer treatment and control plots at $P < 0.05$.

centrations. Inorganic soil N concentration rapidly increased in the $\text{N}_3\text{P}_4\text{K}_1$ plot compared to the control (Figure 2), whereas soil N availability was not affected by the PK addition. Mean C concentration in litterfall components was slightly lower in the $\text{N}_3\text{P}_4\text{K}_1$ (50.8 %) and P_4K_1 (50.5 %) plots than in the control (51.1 %) plot, but the concentration was not affected by the N addition in compound fertilizer (Table 2, Figure 3). This result is in line with another study reporting that the C concentration of needle litter was a poor indicator of fertilizer response with a similar C concentration between fertilized (53.9 %) and unfertilized (53.8 %) in radiata pine (*P. radiata*) plantations (Smaill et

Table 2. Results of ANOVA on the effects of compound fertilizer types (F), sampling month (M), and litterfall component (C) on litterfall C and N dynamics following compound fertilizer application in a red pine stand.

Source	df	C concentration	N concentration	C/N ratio	C fluxes	N fluxes
F	2	0.3111	0.0038	0.0053	0.2706	0.5994
M	3	0.0017[†]	<0.0001	<0.0001	<0.0001	<0.0001
C	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
F×M	6	0.8742	0.4423	0.8549	0.8350	0.5246
F×C	10	0.9561	0.0371	0.0650	0.3788	0.8969
M×C	15	0.8174	<0.0001	<0.0001	0.0001	<0.0001
F×M×C	30	0.8300	0.2747	0.1589	0.9850	0.9508

[†]Bold values denote a significance at $P < 0.05$.

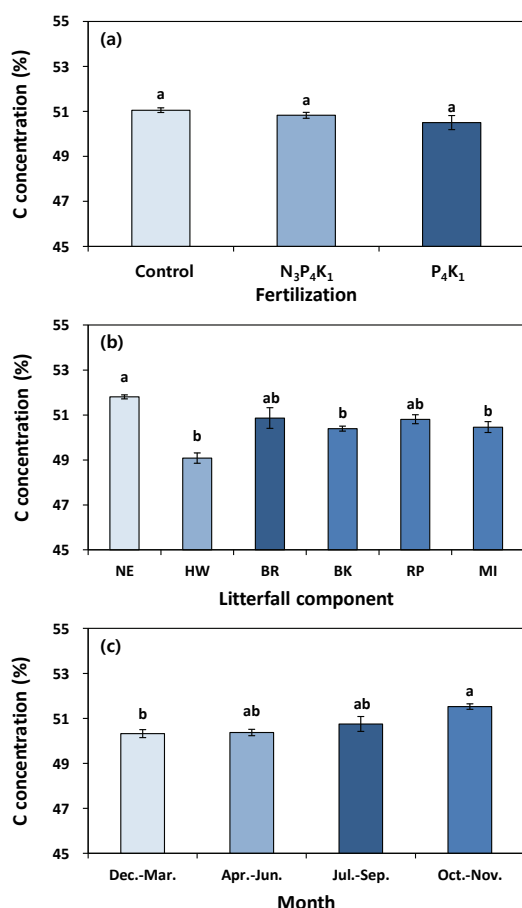


Figure 3. Carbon concentration of fertilizer treatment (a), litterfall component (b, NE: needle; HW: hardwood leaf; BR: branches; BK: bark; RP: reproduction; MI: miscellaneous) and sample months (c) following compound fertilizer application in a red pine stand. Vertical bars represent standard error. Different letter on the bars represents a significant difference between fertilizer treatments (a), litterfall components (b), or months (c) at $P < 0.05$.

al., 2008). Regardless of fertilization, the difference in C concentration of litterfall components in this red pine stand could occur be the result of genetic and environmental factors such as litterfall components and sampling month. For example, the lower C concentration (49.1 %) in hardwood litter compared with needle litter (51.8 %) could be due to the high N concentration (1.01 %) of hardwood litter compared with the needle litter (0.63 %). Also, the higher C concentration (51.5 %) of the litterfall components in the heavy litter season compared with C concentration (50.3-50.7 %) in other sampling months. This result could be attributed to nutrient resorption before needle abscission (Pooter and De Jong, 1999; Baek et al., 2018).

The N concentration of litterfall components showed

significant two-factor interactions ($F \times C$; $M \times C$) (Table 2). The N concentration in the needle litter appeared to be unaffected by the N addition in compound fertilizer. In the previous study, the N concentration of leaf litterfall in oak stands appeared to exert no discernible effect with various rates of compound fertilizer (Kim et al., 2013a) because the N concentration in the leaf litter is controlled by various combinations of factors, including fertilization, tree growth status, climatic factors, nutrient dilution effect by increased needle production and N resorption rates (Berg and Laskowski, 2006; Baek et al., 2018). In contrast to this finding, the N concentration of needle litter in radiata pine was significantly higher in fertilized (0.84 %) than in unfertilized (0.79 %) stands (Smaill et al., 2008) because soil N availability increased by fertilization tends to produce high N concentrations in needle litter (Sariyildiz and Anderson, 2005; Baek et al., 2018). Although N concentration in needle litter was not affected by N addition, mean N concentration over all litterfall components increased in the $N_3P_4K_1$ (0.71 %) and P_4K_1 (0.68 %) plots compared with the control (0.63 %) plots. This increase in N concentrations in all litterfall components could be attributed to the reproduction and miscellaneous litter parts which were highly N responsive in $N_3P_4K_1$ plots (Figure 5). In addition, N concentration in the reproduction litter in the P_4K_1 plot might be affected by P fertilization as well, which can enhance soil N availability by increasing the activity of free living N_2 -fixing soil microbes (Sardans et al., 2017).

The N concentration in the litterfall components was affected by the sampling month (Table 2). The N concentration in needle litter was significantly higher in the growing season than the other seasons (Figure 4). Kim et al. (2013b) reported that the high N concentration in needle litter during the growing season could be due to the high proportion of green foliage fluxes. Meanwhile, the C/N ratio of litterfall components was significantly lower in the $N_3P_4K_1$ and P_4K_1 plot than in the control plot. This result suggests that the $N_3P_4K_1$ and P_4K_1 additions were related to a change in the C/N ratio by producing increased N concentrations in the litterfall components. Furthermore, the C/N ratio among litterfall components was significantly higher in the bark litter than in the other litterfall components because of significantly low N concentration compared with other litterfall components (Figure 5).

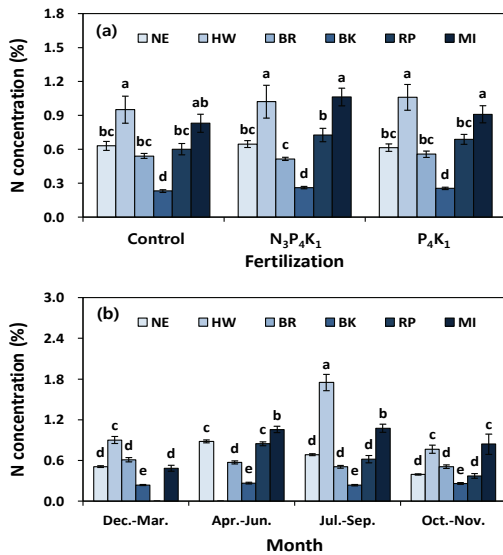


Figure 4. Nitrogen concentration and litterfall component with fertilizer treatment (a) and sampling month (b, NE: needle, HW: hardwood leaves; BR: branches; BK: bark; RP: reproduction; MI: miscellaneous) following compound fertilizer application in a red pine stand. Vertical bars represent standard error. Different letter on the bars represents a significant difference between fertilizer treatments (a) or months (b) at $P < 0.05$.

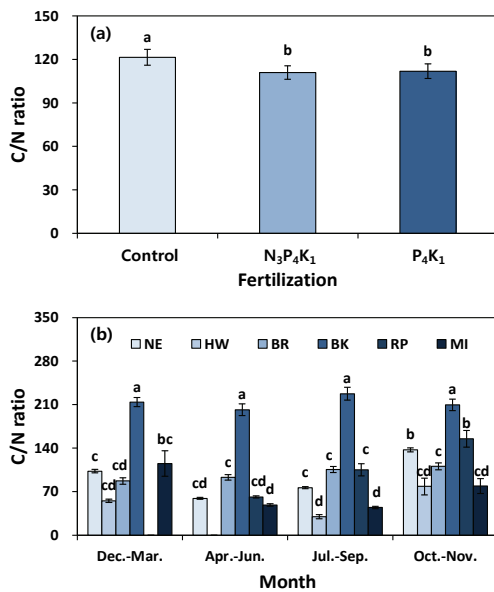


Figure 5. C/N ratio by fertilizer treatment (a) and sampling month (b, NE: needle, HW: hardwood leaves; BR: branches; BK: bark; RP: reproduction; MI: miscellaneous). Vertical bars represent standard error. Different letter on the bars represent a significant difference between fertilizer treatments (a) or months (b) at $P < 0.05$.

2. Carbon and nitrogen fluxes via litterfall components

Total mean C and N fluxes via litterfall components for the study periods were not significantly different between

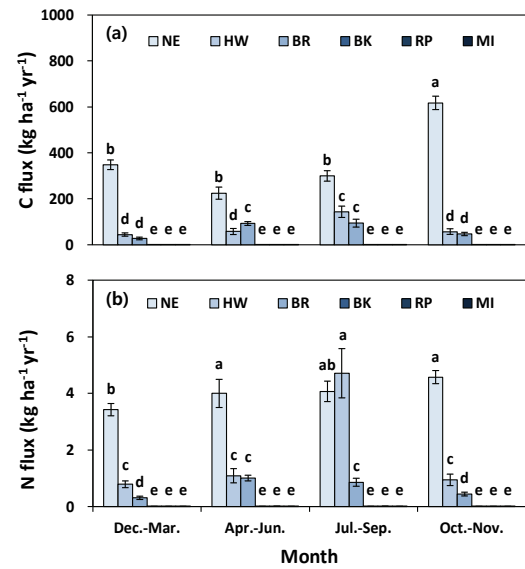


Figure 6. Carbon (a) and nitrogen fluxes (b) by sampling month and via litterfall components (NE: needle, HW: hardwood leaves; BR: branches; BK: bark; RP: reproduction; MI: miscellaneous) following fertilizer application in a red pine stand. Vertical bars represent standard error. Different letters on the bars indicate a significant difference in carbon flux (a) and nitrogen flux (b) between months (c) at $P < 0.05$.

the fertilizer treatment (N₃P₄K₁, P₄K₁) plots and the control plot over the two years, except for the N fluxes via reproduction litter in the N₃P₄K₁ plot (Table 3). The similar C and N fluxes via litterfall components between the fertilizer plots and the control plot could be due to the short period of the fertilization trials for two years (Lee and Son, 2006) or to the closed canopy of the mature pine stands. Another study reported that there was no needle litterfall response to the combined fertilization of N and P sources in loblolly pine stands on a high soil N availability (Vose and Allen, 1991). In contrast to the other litterfall components, the N fluxes via reproduction litter such as male strobili significantly increased by the N addition in compound fertilizer (Table 3). Total mean C and N fluxes were 2,021 kg C ha⁻¹ year⁻¹ and 24.878 kg N ha⁻¹ year⁻¹ for the control, 1,959 kg C ha⁻¹ year⁻¹ and 26.078 kg N ha⁻¹ year⁻¹ for the N₃P₄K₁ and 2,201 kg C ha⁻¹ year⁻¹ and 27.822 kg N ha⁻¹ year⁻¹ for the P₄K₁ plots, respectively. Total C fluxes in these study fall within the range reported for other red pine forests (2,020-2,800 kg C ha⁻¹ year⁻¹) in Korea (Kim et al., 2009), but are slightly lower than the global mean value (about 2,500 kg C ha⁻¹ year⁻¹) of coniferous forests in a warm-temperate climate (Bray and Gorham, 1964).

Table 3. Carbon and nitrogen fluxes via litterfall components by compound fertilizer types.

Nutrient	Year	Treatment	Litterfall components (kg ha ⁻¹ yr ⁻¹)						Total	
			Needle	Hardwood leaf	Branches	Bark	Reproduction	Miscellaneous		
Carbon	2012	Control	1331.9 (121.4)	147.7 (49.1)	171.6 (44.9)	1.28 (0.030)	2.04 (0.08)	1.17 (0.07)	1655.8 (174.2)	
		N ₃ P ₄ K ₁	1248.1 (126.5)	263.8 (59.8)	185.8 (40.0)	1.24 (0.03)	2.32 (0.16)	1.03 (0.04)	1702.4 (175.5)	
		P ₄ K ₁	1421.4 (141.7)	217.5 (50.1)	189.1 (43.2)	1.19 (0.03)	2.09 (0.16)	1.16 (0.08)	1832.6 (215.1)	
	2013	Control	1650.8 (184.1)	393.3 (145.3)	338.5 (54.9)	1.27 (0.06)	1.93 (0.12)	1.11 (0.06)	2387.1 (320.4)	
		N ₃ P ₄ K ₁	1517.6 (234.0)	320.3 (103.4)	373.3 (82.8)	1.29 (0.02)	2.19 (0.03)	1.02 (0.03)	2215.7 (333.2)	
		P ₄ K ₁	1774.7 (172.9)	480.2 (84.4)a	310.8 (79.4)	1.20 (0.03)	2.06 (0.07)	1.08 (0.04)	2570.1 (272.4)a	
	Mean	Control	1491.4 (144.5)a	270.5 (89.3)a	255.0 (49.5)a	1.24 (0.04)a	1.99 (0.08)a	1.14 (0.03)a	2021.4 (240.4)a	
		N ₃ P ₄ K ₁	1382.9 (177.4)a	292.0 (71.5)a	279.5 (60.4)a	1.27 (0.028)a	2.25 (0.09)a	1.03 (0.03)a	1959.1 (245.3)a	
		P ₄ K ₁	1598.0 (152.4)a	348.9 (62.1)a	250.0 (60.5)a	1.19 (0.03)a	2.08 (0.09)a	1.12 (0.02)a	2201.3 (239.0)a	
	Nitrogen	2012	Control	12.755 (1.404)	3.447 (1.461)	1.815 (0.398)	0.010 (0.000)	0.022 (0.002)	0.020 (0.000)	18.05 (2.718)
			N ₃ P ₄ K ₁	12.440 (1.110)	7.000 (2.350)	1.868 (0.389)	0.010 (0.000)	0.032 (0.005)	0.020 (0.003)	21.367 (3.102)
			P ₄ K ₁	13.770 (1.456)	4.948 (0.921)	1.860 (0.425)	0.010 (0.000)	0.028 (0.002)	0.018 (0.002)	20.630 (2.601)
2013		Control	19.378 (3.257)	8.898 (4.148)	3.373 (0.481)	0.005 (0.002)	0.018 (0.002)	0.020 (0.003)	31.688 (6.700)	
		N ₃ P ₄ K ₁	18.035 (3.020)	8.927 (3.199)	3.680 (0.734)	0.010 (0.000)	0.020 (0.000)	0.018 (0.002)	30.690 (6.136)	
		P ₄ K ₁	20.002 (1.695)	11.898 (2.365)	3.062 (0.682)	0.008 (0.002)	0.022 (0.003)	0.017 (0.002)	35.010 (3.832)	
Mean		Control	16.067 (2.275)a	6.173 (2.718)a	2.595 (0.427)a	0.007 (0.002)a	0.018 (0.002)b	0.018 (0.002)a	24.878 (4.663)a	
		N ₃ P ₄ K ₁	15.237 (2.053)a	7.962 (2.473)a	2.775 (0.556)a	0.010 (0.001)a	0.028 (0.003)a	0.018 (0.002)a	26.028 (4.345)a	
		P ₄ K ₁	16.887 (1.516)a	8.425 (1.492)a	2.460 (0.542)a	0.010 (0.001)a	0.025 (0.002)ab	0.018 (0.002)a	27.822 (3.098)a	

Values in parentheses represent standard error. Different letter among treatments represent a significant difference between the fertilizer treatments at $P < 0.05$.

The C and N fluxes via litterfall components demonstrated a significant two-factor interaction ($M \times C$) (Table 2). The seasonal C and N fluxes via needle litter showed maximum values in heavy litterfall season compared with the other seasons (Figure 6). This pattern fits into the findings from many studies for coniferous tree species because of the natural senescence of temperate forests (Kim et al., 2005). In contrast to needle litter, C and N fluxes via hardwood leaf litter were highest in the late growing season (Figure

6). However, seasonal patterns of C and N fluxes via woody and miscellaneous litter were irregular throughout the year because the flux patterns of this litter type were attributed to forest disturbance factors (Sato, 2004).

Conclusions

The C concentration of litterfall components was not affected by the N₃P₄K₁ and P₄K₁ additions, whereas N

concentration of litterfall components increased with N₃P₄K₁ compared with the control. The C/N ratio of litterfall components was easily influenced by N₃P₄K₁ and P₄K₁ additions with a lower C/N ratio compared with the control treatments. However, the C and N fluxes via litterfall components were not related to the N₃P₄K₁ and P₄K₁ additions over the study period, except for reproduction litter, which was most sensitive to the N₃P₄K₁ additions among litterfall components. The results indicated that the C response of litterfall components could have a minimal impact on N₃P₄K₁ addition, whereas N responses could differ considerably by N addition in a red pine stand.

Acknowledgments

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