J. Korean Soc. For. Sci. Vol. 108, No. 3, pp. 296~301 (2019)
https://doi.org/10.14578/jkfs.2019.108.3.296

한국산림과학회지
JOURNAL OF KOREAN SOCIETY OF FOREST SCIENCE
ISSN 2586-6613(Print), ISSN 2586-6621(Online)
http://e-journal.kfs21.or.kr

Phosphorus and Base Cation Inputs through Litterfall Components in Pine Forests after Tree Removal Due to Pine Wilt Disease Disturbance

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Abstract: This study was conducted to measure litterfall and nutrient (P, K, Ca, Mg) inputs under varying degrees of disturbance by pine wilt disease in pine forests in southern Korea. Litterfall was collected to evaluate nutrient responses at different intensities of disturbance (various levels of basal area) by pine wilt disease across 2 years. Phosphorus, Ca, and Mg concentrations in needle litterfall were positively correlated ($p < 0.05$) with decreased disturbance intensities (increased basal area) depending on the time of sampling, whereas the nutrient concentrations in other litterfall components (branches, bark, reproductive organs, and miscellaneous litterfall) were not significantly correlated ($p > 0.05$) with the intensity of pine wilt disease disturbance. Dry weight and nutrient inputs through litterfall components decreased linearly with increasing intensity of disturbance by pine wilt disease ($p < 0.05$), except for the nutrient inputs of branch (K, Ca, Mg) and reproductive organ (K, Ca) litterfall. These results indicate that decreased litterfall across different levels of disturbance may be related to the reduced soil nutrients in pine wilt disease forests.

Key words: *forest disturbance; litterfall; nutrient cycle; pine wilt disease; red pine*

Introduction

Litterfall is an important component of the nutrient cycle in forest ecosystems because it contributes nutrient return (Berg and Laskowski, 2006). However, disturbances such as defoliation or tree death due to forest insects or disease may lead to changes in nutrient inputs through litterfall on the forest floor and in the soil (Morehouse et al., 2008; Lardo-Monserrat et al., 2016; Bueis et al., 2018). Generally, nutrient inputs through litterfall following forest disturbance tend to reduce to a degree roughly proportional to the degree of dead or removed trees (Inagaki et al., 2008; Kim et al., 2011; Lardo-Monserrat et al., 2016).

Pine wilt disease has become the most serious threat to Korean pine ecosystems since it was first reported in late 1988 (Enda, 1989). In forests disturbed by pine wilt disease, there are varying degrees of disturbance in small-scale stands because the removal of infected trees through selective or sanitation cuttings is an important control strategy (Jeon et al., 2011; Kwon et al., 2011). Thus, forests disturbed by pine wilt disease are likely to be modied nutrient inputs through litterfall after removing infected trees (Kim et al., 2011; Kim et al., 2019).

Phosphorus (P) and base cations, such as potassium (K), calcium (Ca), and magnesium (Mg) are important macronutrients for tree growth and forest productivity (Binkley and Fisher, 2013). Although P and base cation inputs through litterfall are major nutrient sources in forest soils (Berg and Laskowski, 2006; Kim et al., 2013), little is known about nutrient responses under different intensities of pine wilt disease disturbance. In addition, understanding nutrient inputs through litterfall in pine wilt disease-disturbed stands is important because the varying levels of infected tree removal may alter nutrient cycling processes through litterfall. The objectives of this study were to examine the effect of different intensities of disturbance due to pine wilt disease in terms of nutrient inputs through litterfall components.

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Material and Methods

1. Study site

This study was conducted in matured Korean red pine (*Pinus densi*flora S. et Z.) stands (35°12′21″ N, 128°10′24″ E, a.s.l. 150 m) in the Wola National Experimental Forest administered by the Forest Biomaterial Research Center, National Institute of Forest Science, southern Korea. The average annual precipitation in this area is 1,490 mm yr^{-1} and the temperature is 13.1°C. The soil was a slightly dry, dark-brown forest soil (USDA Soil Taxonomy: Inceptisols). The study site was in an area that has been severely damaged by pine wilt disease since its outbreak in 1998 (Jeon et al., 2011; Jeong et al., 2013). More information on the study site is reported elsewhere (Jeong et al., 2013; Kim et al., 2019).

Nine Korean red pine plots of 10 × 10 m with varying intensity of damage from pine wilt disease-disturbed stands (Table 1) were established on similar slopes and aspects to minimize spatial variation of the study plots. These plots included different intensities of disturbance because of the selective cutting of the infected and dead pine trees on a small stand scale. Tree densities ranged from 300 trees ha^{-1} for severely disturbed plots to 2,500 trees ha^{-1} for slightly disturbed plots. The mean diameter at breast height (DBH) was highest (16.36 cm) at a density of 1,300 trees ha^{-1} and lowest (12.56 cm) at 1,100 trees ha^{-1}. Stand basal area was highest (35.9 m^2 ha^{-1}) at 2,100 tree ha^{-1} and lowest (4.2 m^2 ha^{-1}) at 300 tree ha^{-1} (Table 1).

2. Nutrient analysis of litterfall components

Litterfall inputs were measured by three circular litter traps (0.25 m^2 area; total, 27 litter traps) installed 60 cm above the forest floor at each plot on May 29, 2009.Litter was collected 13 times (Jul. 27; Sep. 18; Oct. 22; Nov. 18; Dec.23, 2009; Mar. 28; May 20; Jul. 20; Sep. 17; Oct. 26; Nov. 11; Dec. 10, 2010; Apr. 13, 2011) for 2 years between May 29, 2009 and Apr. 13, 2011. Litter collected from each trap was oven-dried at 65C for 48 h in the laboratory. All dried samples of litterfall components were separated into needles, bark, reproductive organs (cones and flowers), branches, and miscellaneous, and each component was weighed. The litter samples were combined for two part of each year (Jul.–Nov., Dec.–Jun.) because in severely disturbed plots, the amount was limited for chemical analysis. The composited litterfall components were ground in a Wiley mill. Phosphorus, K, Ca, and Mg concentrations were measured via ICP-OES (Perkin Elmer Optima 5300DV, Shelton, CT, USA) after dry-ashing 0.5

Table 1. Selected stand and soil characteristics of different intensities of disturbance by pine wilt disease.

Disturbed intensity	Tree density (tree ha^{-1})	Basal area (m^2 ha^{-1})	Mean DBH (cm)	Available P (mg kg^{-1})	Exchangeable (cmolc kg^{-1})		
					K^+	Ca^{2+}	Mg^{2+}
Slight	2,100	35.9*	14.08 (0.98)	2.35 (0.22)abc	0.12 (0.01)a	3.32 (0.25)a	1.93 (0.15)a
	1,800	35.5	15.40 (0.90)	2.79 (0.77)ab	0.16 (0.01)a	3.83 (0.20)a	1.60 (0.24)ab
	2,500	33.1	12.60 (0.61)	1.81 (0.27)bcd	0.14 (0.02)a	3.03 (0.17)ab	1.21 (0.10)b
	1,300	28.6	16.36 (0.94)	3.87 (0.75)a	0.16 (0.01)a	4.02 (0.20)a	1.62 (0.13)ab
	1,500	25.3	14.22 (0.91)	1.57 (0.18)bcd	0.13 (0.02)a	2.95 (0.23)ab	1.48 (0.05)ab
	1,100	14.3	12.56 (0.98)	0.74 (0.21)cd	0.10 (0.02)a	1.10 (0.16)c	0.58 (0.02)c
	800	13.9	14.54 (1.18)	0.85 (0.07)cd	0.09 (0.02)a	1.17 (0.19)c	0.52 (0.09)c
	500	9.7	15.36 (1.46)	0.83 (0.13)cd	0.29 (0.12)a	1.63 (0.18)bc	0.63 (0.03)c
Severe	300	4.2	13.23 (0.54)	1.02 (0.12)bcd	0.17 (0.02)a	2.60 (0.83)abc	0.63 (0.05)c

DBH, diameter at breast height (1.2 m). Parenthesis values are standard error. Different letters among each column represent a significant difference at $p < 0.05$. *The data were reused from Kim et al. (2019).

g of the ground material at 470°C for 4 h and digesting the ash with 3 mLof concentrated 5 MHCl (Kalra and Maynard, 1991). Total nutrient inputs through litterfall components were calculated by multiplying each litterfall component weight by the nutrient concentration.

3. Soil properties

Soil nutrient concentrations under different intensities of disturbance by pine wilt disease were measured from soil samples collected at a depth of 20 cm using an Oakfield soil sampling probe during the summer of 2009. The soil samples were sieved through a 2 mm mesh. Soil P concentration extracted by NH_4F and HCl solutions was determined using a UV spectrophotometer (Jenway 6505, Staffordshire, UK). Soil-exchangeable cations (K^+, Ca^{2+}, and Mg^{2+}) extracted by NH_4Cl solution (Kalra and Maynard, 1991) were determined through ICP-OES (Perkin Elmer Optima 5300DV, Shelton, CT, USA).

4. Data analysis

Relationships between the nutrient concentrations of litterfall components and the different intensities of disturbance (basal area) were analyzed by Pearson correlation analysis. The linear relationships between nutrient inputs through the litterfall components and the different disturbed intensities were examined at $p < 0.05$ (SAS Institute Inc. 2003).

Results and Discussion

1. Nutrient concentration of litterfall components

There was a positive correlation ($p < 0.05$) between the nutrient concentrations of needle litterfall and different intensities of disturbance (levels of basal area) in pine wilt disease-disturbed stands, depending on the time of samplings (Figure 1). The nutrient concentration of needle litterfall was generally greater in the slightly disturbed plots than in the severely disturbed plots. Phosphorus and Mg concentrations of needle litterfall sampled in Jul.–Nov. 2009, and the Ca concentration of needle litterfall sampled in Dec. 2010–Jun. 2011 were positively correlated with increased basal area (Figure 1). Low concentrations of P,

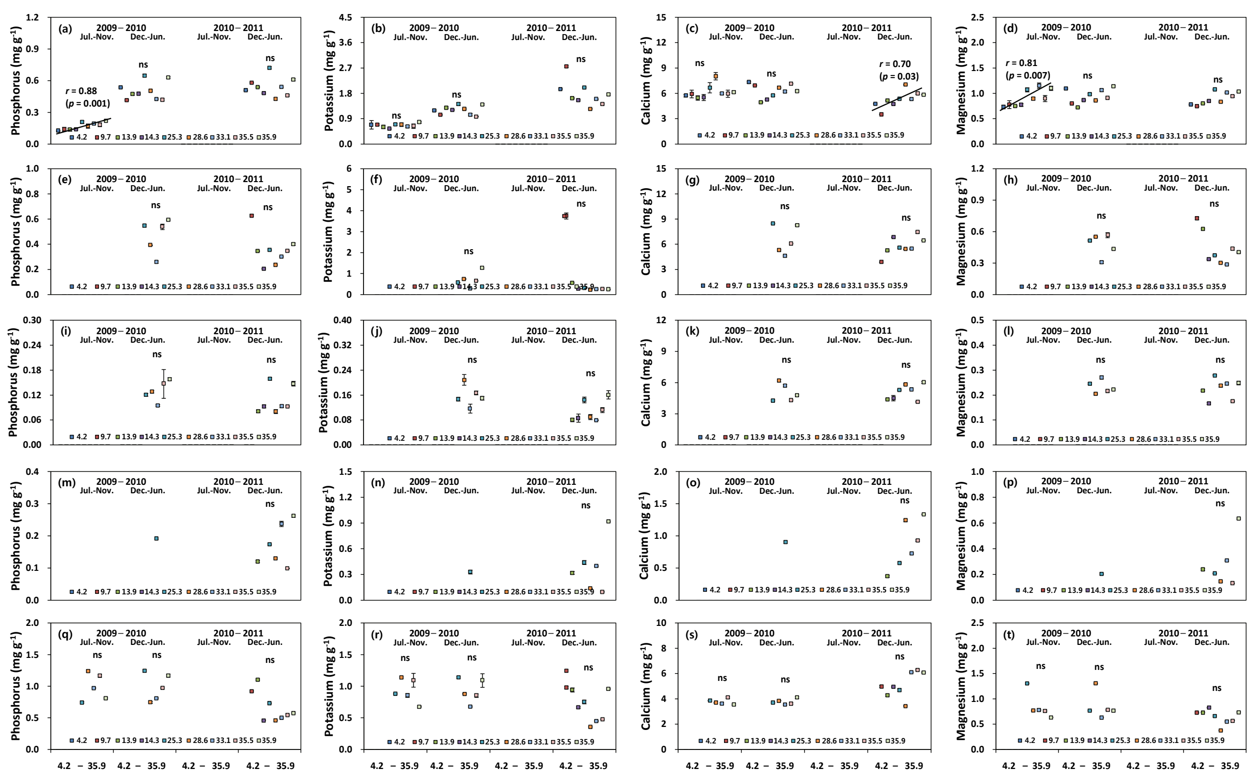

Figure 1. Correlation between nutrient concentration forlitterfall components [needles (a, b, c, d), branches (e, f, g, h), bark (i, j, k, l), reproduction (m, n, o, p), miscellaneous (q, r, s, t)] and different intensities of disturbance (basal area) by pine wilt disease. Vertical bars represent standard error. ns: non-significance at $p < 0.05$.

Ca, and Mg in the needle litter of severely disturbed plots may be due to poor nutrient uptake from mineral soil areas or increased resorption of nutrients under poor soil nutrient conditions. Soil nutrient conditions (P, Ca, and Mg) in this study site declined with increased intensity of disease disturbance (Table 1). Similarly, P and Ca concentrations in the litterfall of Norway spruce and Sitka spruce stands were associated with soil nutrient status at the sites (Hansen et al., 2009). Furthermore, needle litter from nutrient-poor sites has been shown to possess a higher nutrient resorption efficiency compared with species from nutrient-rich soil environments (Yuan and Chen, 2015). However, the nutrient concentrations of branches, bark, reproductive organs, and miscellaneous litterfall were not significantly affected ($p > 0.05$) by different intensities of disturbance by pine wilt disease. Previous studies found that the nutrient concentration of woody litterfall was weakly associated with soil nutrient status at the sites (Kim et al., 2013; Park et al., 2019).

2. Nutrient input through litterfall components

Annual mean dry weight and nutrient (P, K, Ca, and Mg) inputs through litterfall components were linearly ($p < 0.05$) related to the intensity of disturbance from pine wilt disease, except for branch and reproductive organ litterfall sampled in 2010–2011 (Figure 2). The reduced litterfall may be associated with a considerable difference in the basal area induced by selective cutting of infected trees. Similarly, studies have reported that nutrient inputs through litterfall in pine stands is proportional to the levels in the basal area (Kim, 2016; Lardo-Monserrat et al., 2016).

The slope coefficient (i.e., coefficient b) of the regression equations to estimate the dry weight of litterfall components was highest in needles (2009–2011: 89.144; 2010–2011: 57.335), followed by branches (2009–2011: 15,657), miscellaneous (2009–2011: 25.117; 2010–2011: 22.342), reproductive organs (2009–2011: 12.467; 2010–2011: 24.138), and bark (2009–2011: 12.019; 2010–2011: 10.623) litterfall, respectively (Figure 2). This indicates that the reduction of

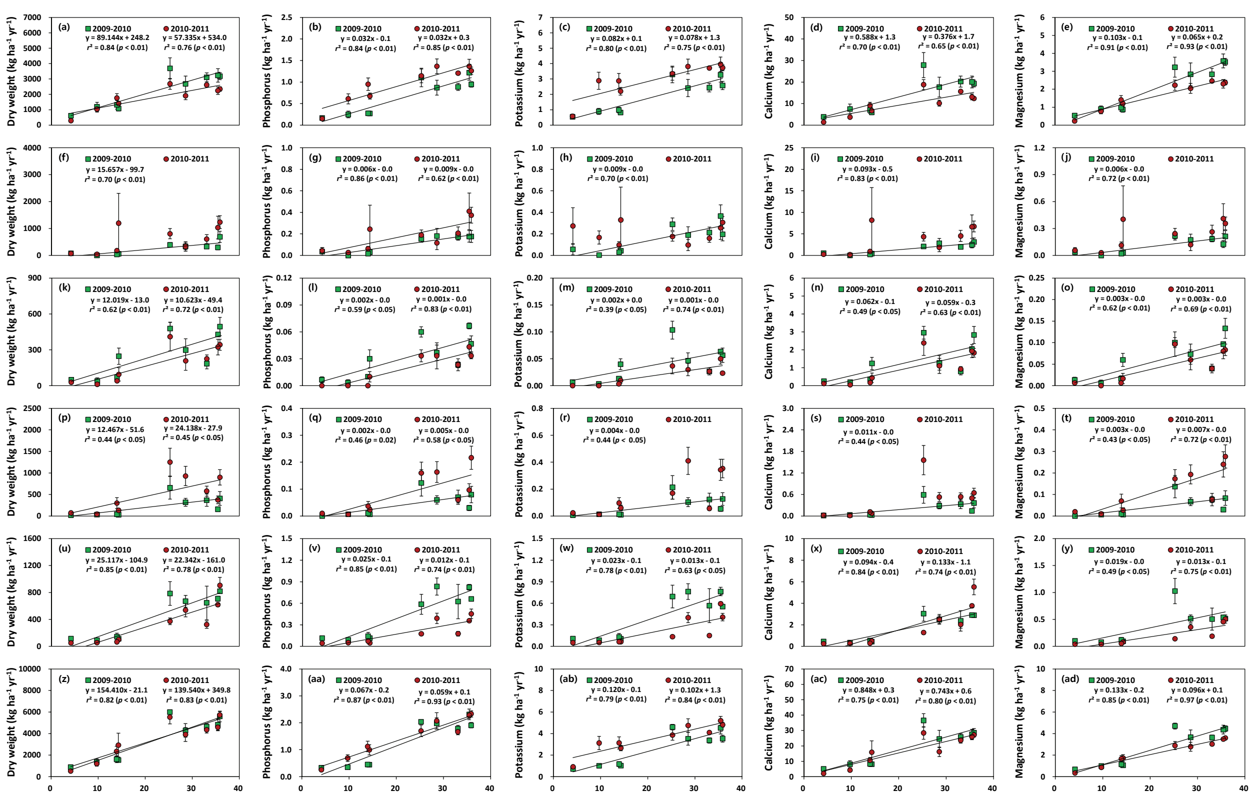

Figure 2. Linear relationships between dry weight, phosphorus, potassium, calcium, and magnesium inputs through litterfall components [needles (a, b, c, d, e), branches (f, g, h, i, j), bark (k, l, m, n, o), reproduction (p, q, r, s, t), miscellaneous (u, v, w, x, y), total (z, aa, ab, ac, ad)] and different intensities of disturbance (basal area) by pine wilt disease. Vertical bars represent standard error. Linear regressions represent significance at $p < 0.05$.

total litterfall with increasing disturbance may be largely due to decreased needle litterfall. Previous studies have shown that C and N inputs through litterfall components in pine wilt disease-disturbed forests are determined by differences in needle litterfall (Kim et al.,2011, Kim et al., 2019). In contrast to needle litterfall, K, Ca, and Mg inputs through branch litterfall, and Ca inputs through reproductive organ litterfall were not linearly related to different intensities of disturbance ($p > 0.05$). This may be due to high spatial and temporal variation of these litterfall components (Navarro et al., 2013).

The annual base cation inputs (3.15 kg K ha^{-1} yr^{-1}, 15.85 kg Ca ha^{-1} yr^{-1}, and 2.94 kg Mg ha^{-1} yr^{-1}) through needle litterfall in slightly disturbed plots (2,500 trees ha^{-1}) were lower than those of needle litterfall (4.71 kg K ha^{-1} yr^{-1}, 35.09 kg Ca ha^{-1} yr^{-1}, 4.37 kg Mg ha^{-1} yr^{-1}) in other red pine stand (Kim et al., 2013). Low nutrient inputs in this study site may be associated with the low nutrient concentration of needle litter in stands disturbed by pine wilt disease, which is mainly attributed to the soil nutrient status at thesites (Table 1). In addition, the mean nutrient concentration of needle litter was lower in stands disturbed by pine wilt disease (1.1 mg g^{-1} for K, 5.8 mg g^{-1} for Ca and 0.9 mg g^{-1} for Mg) compared with other natural red pine stands (1.2 mg g^{-1} for K, 9.0 mg g^{-1} for Ca and 1.1 mg g^{-1} for Mg) reported by Kim et al. (2013).

Conclusions

This study revealed that P and base cation inputs through litterfall components were dependent on the intensity of disturbance (levels of basal area) by pine wilt disease. Phosphorus, Ca, and Mg concentrations of needle litterfall components were significantly correlated with different intensities of pine wilt disease, whereas K was less sensitive than the other nutrients to different intensities of disturbances. The reduction in dry weight and nutrient returns through litterfall components was linearly related to different levels of disturbance, except for nutrient inputs through branch and reproductive organ litterfall. These results suggest that a linear decrease in nutrient inputs through litterfall components may reduce soil nutrients with increasing intensity of disturbance by pine wilt disease.

Acknowledgements

We thank the students of forest soil lab in Gyeongnam National University of Science and Technology for the assistance in the collection of data.

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Manuscript Received : June 27, 2019
First Revision : July 27, 2019
Accepted : July 29, 2019