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Vegetation Type Effects on Nutrient Status and Stoichiometry of the Forest Floor in Southern Korea

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Abstract

Quantitative evaluation of nutrient status and stoichiometry on the forest floor is a good indicator of litter quality in various vegetation types. This study was conducted to determine the effects of vegetation type on the nutrient concentration and stoichiometry of forest floors at a regional scale. Forest floor samples were collected from four vegetation types of evergreen coniferous forests including *Cryptomeria japonica*, *Chamaecyparis obtusa*, evergreen broadleaf, and bamboo spp. forests in southern Korea. The dry weight of the forest floor was higher in the *C. japonica* and *C. obtusa* forests than in the evergreen broadleaf and bamboo forests. The mean carbon (C) concentrations of the forest floor were highest in the broadleaf forest, followed by the bamboo forest, *C. japonica* and *C. obtusa* forests. Mean nitrogen (N) and phosphorous (P) concentrations in the the coniferous forests were lower than those in the broadleaf and bamboo forests. The mean C:N ratio was the highest in *C. obtusa* forest (118±25), followed by *C. japonica* (66±6), evergreen broadleaf (41±1), and bamboo (30±1) forests. However, C:P and N:P ratios were lower in the coniferous forests than in the broadleaf forest indicating that the stoichiometry of the forest floor varies across vegetation types. The C, N, and P stocks on the forest floor were higher in the *C. obtusa* forest than in the broadleaf or bamboo forests. These results highlight that vegetation type-dependent stoichiometric ratio is an useful indicator for understanding interspecific difference in quality and quantity of the forest floor.

Key Words: bamboo, *Chamaecyparis obtusa*, *Cryptomeria japonica*, nutrient cycling, nutrient ratio

Introduction

The forest floor composed of organic matter at various stages of litter decomposition serves as a nutrient reservoir, habitat, and energy source for animals and microbes in forest soils (Herrero et al. 2016; Takahashi 2021). Nutrient composition and physical characteristics induced by vegetation type can affect decomposition processes and development on the forest floor (Manzoni et al. 2008). For example, litter from different vegetation types decomposes at different rates because the decomposition rates of litter are influenced by many interacting biotic and abiotic factors, such as litter quality, composition of the decomposer community, and microclimate (Manzoni et al. 2008; Erickson et al. 2014; Herrero et al. 2016).

Quantitative evaluation of the nutrient status of the forest floor is important because carbon (C), nitrogen (N), and phosphorous (P) availability in forest soils strongly depends

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on the litter decomposition and stoichiometry of the forest floor (Manzoni et al. 2010). The stoichiometry of the forest floor (e.g., C:N, C:P, and N:P ratios) is useful for estimating the quality of decomposing litter materials. In addition, differences in stoichiometry are good indicators of the conditions and processes of litter decomposition on forest floors. Thus, the stoichiometry of the forest floor may assist in understanding biochemical cycles in forest ecosystems. The nutrient status of the forest floor varies in different vegetation types owing to interspecific differences in litter production, nutrient contents and decomposition rates (Manzoni et al. 2008; Takahashi et al. 2021). Although stoichiometry and nutrient stocks in forest ecosystems play pivotal roles in nutrient cycling, stoichiometry and nutrient stocks within the forest floor have received less attention in Korean forest ecosystems.

Coniferous, evergreen, broadleaf, and bamboo forests in the warm-temperate forest zone of Korea are important biomass resources because of their faster growth compared to other temperate vegetation types (Han et al. 2017; Kim et al. 2019). Vegetation growth and ecosystem carbon cycle modellings are constrained by soil nutrient status, and thus, evaluating the nutrient status, such as the stoichiometry and nutrient concentration of forest floors, by different vegetation types is important. Most previous studies on stoichiometry are performed using meta-data, which may use different analytical methods and equipment (e.g. Erickson et al. 2014; Takahashi 2021), but there are very limited studies based on observations with the same sampling protocol and analysis on a regional scale. The objective of this study was to understand how vegetation type affects the nutrient status and stoichiometry of the forest floor in warm-termperate forest regions of southern Korea.

Materials and Methods

Study site

The study sites were located in twelve regions (Goseong-gun, Namhae-gun, Jangseong-gun, Jangheung-gun, Seoguipo-si, Hadong-gun, Gwangyang-gun, Bosung-gun, Sacheon-si, Wanju-gun, Jinju-si, and Jinhae-si) for *Crypromeria japonica* and *Chamaecyparis obtusa* forests, two regions (Goseong-gun and Jindo-gun) for evergreen broadleaf forests, and two regions (Jinju-si and Damyang-gun) for bamboo spp. forests in southern Korea (Table 1). The mean (1991-2020) annual temperature and precipitation of the fourteen study sites ranged from 12.5°C to 16.9°C and from 1296 to 1989 mm yr^{-1} (Korea Meteorological Administration 2024).

Nutrient analysis of forest floor

The experimental design consisted of three 20 m×20 m or 20 m×10 m plots at each site. The forest floor, consisting of needles, twigs, broad leaves, small branch pieces (<2 cm), bark, and miscellaneous parts (e.g., reproductive fragments), was collected from three random points in each plot using a 900 cm^2 steel quadrat or a 200 cm^2 cylinder in each stand. The organic layer of the forest floor included fresh litter, fermented, and humus layers. The samples were

Table 1. Vegetation types and dominant tree species in the study sites

Vegetation type	Dominant species	No. of sample	Site locations
Evergreen coniferous forest	*Cryptomeria japonica* D.Don.	45	Goseong-gun, Namhae-gun, Jangseong-gun, Jangheung-gun,
Evergreen coniferous forest	*Chamaecyparis obtusa* (Siebold & Zucc.) Endl.	39	Seoguipo-si, Hadong-gun, Gwangyang-gun, Bosung-gun, Sacheon-si, Wanju-gun, Jinju-si, Jinhae-si
Evergreen broadleaf forest	*Machilus thunbergii* Siebold & Zucc, *Neolitsea sericea* (BL). KOIDZ., *Quercus glauca* Thunb.	41	Goseong-gun, Jindo-gun
Bamboo species forest	*Phyllostachys pubescens* Mazel ex Lehaie, *Phyllostachys bambusoides* Siebold & Zucc. *Phyllostachys nigra* var. *henonis* (Bean) Stapf ex Rendle.	32	Jinju-si, Damyang-gun

placed in zipper paper, oven-dried at 65°C, ground in a Wiley mill, and passed through a 40-mesh stainless-steel sieve. C and N concentrations of the ground materials were determined using an elemental analyzer (Flash 2000, Thermo Scientific, Milan, Italy). P concentrations were determined by dry ashing 0.5 g of the ground material at 470°C for 4 h, digesting the ash with 3 mL of concentrated 5 *M* HCl, diluting the digest with 0.25 mL of concentrated HNO_3 and 3 mL of concentrated 5 *M* HCl (Kalra and Maynard 1991), and measuring the concentrations via ICP-OES (Optima 5300DV, Perkin Elmer, Shelton CT, USA). Nutrient storage in the forest floor was calculated by multiplying the nutrient concentrations by the dry weight of the forest floor.

Data analysis

The nutrient concentrations of the forest floor were analyzed using the α general linear model procedure in SAS (SAS Institute 2004) to determine the significance of the vegetation types at $p < 0.05$. Tukey's multiple comparison test was used to compare the treatment means for different vegetation types.

Results and Discussion

The dry weights of the forest floors in the coniferous forests, such as *C. japonica* (23.4±1.6 Mg ha^{-1}) and *C. obtusa* (27.7±1.8 Mg ha^{-1}), were higher than those of broadleaf (10.7±0.6 Mg ha^{-1}) or bamboo (8.3±0.6 Mg ha^{-1}) forests (Table 2). Mean C concentrations in the forest floor were the highest in the broadleaf forest (452±4 mg g^{-1}), followed by bamboo (386±8 mg g^{-1}), *C. japonica* (331±15 mg g^{-1}) and *C. obtusa* (298±13 mg g^{-1}) forests, whereas the N and P concentrations in the coniferous forests were lower than those in evergreen broadleaf or bamboo forests. Although many studies have reported interspecific variations in C concentration by litter quality (Takahashi 2005; Ma et al. 2018), the low C concentration in the coniferous forests might be affected by the interaction of mineral soils and the forest floor due to mineral contamination in the thin forest floor compared to the evergreen broadleaf and bamboo forests. In addition, the forest floors in the coniferous forests contained partially uncovered surface soil. Similar results were observed in *C. obtusa* forests in Japan, where the forest floor was poorly developed because of the small leaflets of rapid physical fragmentation in the early stages of decomposition of freshly fallen litter (Takahashi 2021). The mean C concentration on the forest floor in this study was 366 mg g^{-1}. Another study reported that C concentration on the forest floor in Japan was 446 mg g^{-1} (Takahashi 2005). The ash content of the Korean forest floor appears to be higher than that of the Japanese forest floor.

The mean N concentrations of the forest floors were lower in the coniferous forests than in the evergreen broadleaf and bamboo forests (Table 2). In contrast, the mean P concentration was the highest in the bamboo forest (0.72±8 mg g^{-1}), because of the high P uptake characteristics of the foliage (Baek et al. 2022). Many studies have demonstrated that coniferous forest floors have lower N concentrations than broadleaf forests because of differences in nutrient uptake and resorption before litterfall (Herrero et al. 2016; Takahashi 2021). The N of the forest floor in this study (6.81-13.24 mg g^{-1}) is comparable to that of Japanese forests (10.0-11.5 mg g^{-1}). The N and P concentrations in the forest floor seem to be affected by vegetation type because of differences in litter decomposition, the input of organic

Table 2. Dry weight and nutrient concentrations in the forest floor of four vegetation types

Vegetation type	Dry weight (Mg ha^{-1})	Nutrient concentration (mg g^{-1})		
		Carbon	Nitrogen	Phosphorous
Cryptomeria japonica	23.4±1.6^{a}	331±15^{c}	6.81±0.55^{b}	0.48±0.03^{b}
Chamaecyparis obtusa	27.7±1.8^{a}	298±13^{c}	5.82±0.62^{b}	0.49±0.05^{b}
Evergreen broadleaf species	10.7±0.6^{b}	452±4^{a}	11.69±0.38^{a}	0.50±0.02^{b}
Bamboo species	8.3±0.6^{b}	386±8^{b}	13.24±0.40^{a}	0.72±0.05^{a}

Mean±standard error. Different letters among vegetation types represent a significant difference among four vegetation types at $p < 0.05$.

matter from fine roots developed on the forest floor, annual temperature (Spohn and Stendahl 2022), and microbial biomass (Zederer et al. 2017; Liu et al. 2019). The mean P concentrations in this study (0.48-0.72 mg P g^{-1}) were relatively lower than those in the forest floor (0.5-1.2 mg P g^{-1}) of Japan (Takahashi 2021).

The stoichiometry of the forest floor varies across vegetation types. The mean C:N ratio was the highest in *C. obtusa* forest (118±25), followed by *C. japonica* forest (66±6), evergreen broadleaf (41±1), and bamboo (30±1) forests (Fig. 1a). In contrast to the C:N ratio, the C:P and N:P ratios were lower in the coniferous forests than in the evergreen broadleaf forest (Fig. 1b, c). These results could be due to the different processes of litter decomposition and the composition of the decomposing organic material on the forest floor (Manzoni et al. 2010; Spohn and Stendahhl 2022). The low C:N ratios of the evergreen broadleaf and bamboo forests indicate that net C and N mineralization progresses rapidly during organic matter decomposition (Manzoni et al. 2008). The C:P and N:P ratios varied considerably more than the C:N ratio. The high N:P ratio in the evergreen broadleaf and bamboo forests indicates N-rich and P-poor nutrients in the litter. Based on P concentration, the C:N:P ratios were 742:14:1 for the *C. ja-*

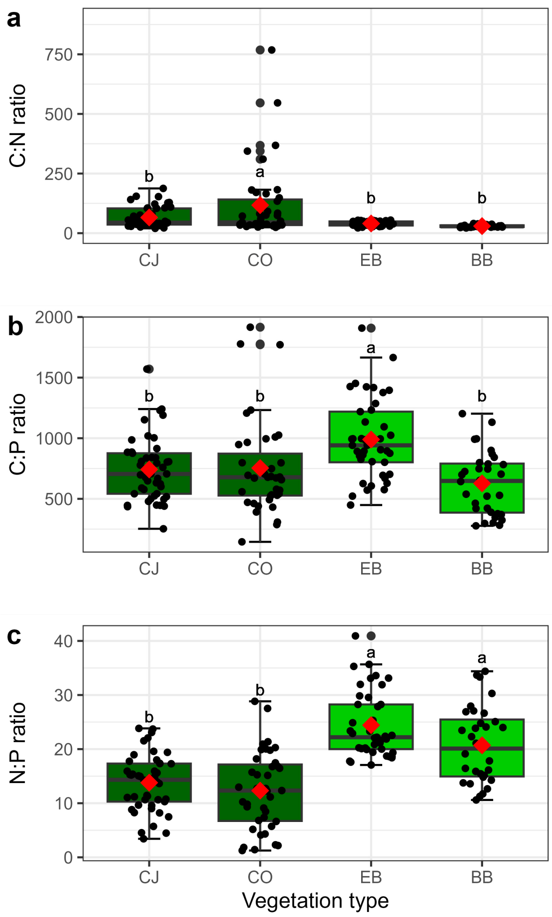

Fig. 1. (a) C:N, (b) C:P, and (c) N:P ratios of the forest floor in four vegetation types (CJ, *Cryptomeria japonica*; CO, *Chamaecyparis obtusa*; EB, Evergreen broadleaved tree species; BB, Bamboo spp.). The box represents the median and the 25th and 75th percentiles, ◇ represents the arithmetic mean, the solid lines extend to 1.5 of the interquartile range. Different letters on the bar represent a significant difference among vegetation types at $p < 0.05$.

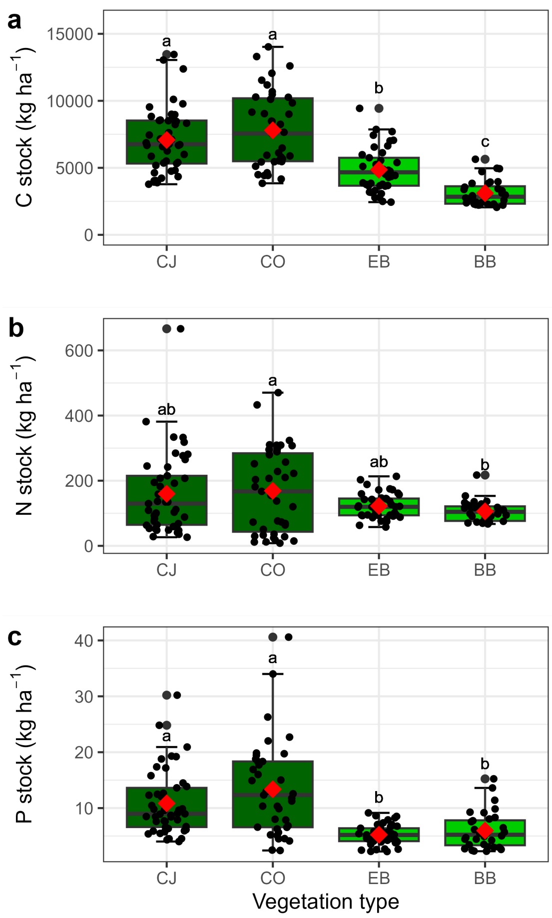

Fig. 2. (a) Carbon, (b) nitrogen and (c) phosphorus stocks of the forest floor in four vegetation types (CJ, *Cryptomeria japonica*; CO, *Chamaecyparis obtusa*; EB, Evergreen broadleaved tree species; BB, Bamboo spp.). The box represents the median, and the 25th and 75th percentiles ◇ represent the arithmetic mean; the solid lines extend to 1.5 of the interquartile range. Different letters on the bar represent a significant difference among the vegetation types at $p < 0.05$.

ponica forest, 754:12:1 for the *C. obtusa* forest, 989:24:1 for the evergreen broadleaf forest, and 627:21:1 for the bamboo forest. These results are lower than the C:N:P ratios of the forest floor (942:19:1 for *C. japonica* forest and 625:19:1 for broadleaf forests) in Japan (Takahashi 2021).

The C and P stocks in the forest floor were higher in the coniferous forests, which had a greater dry weight of the forest floor (Table 2) than in the evergreen broadleaf or bamboo forests (Fig. 2). This was expected because the nutrient stocks of the forest floor were calculated using the dry weight parameter. The C stocks in this study were 7.1±0.4 Mg ha^{-1} for the *C. japonica* forest, 7.8±0.5 Mg ha^{-1} for the *C. obtusa* forest, 4.9±0.3 Mg ha^{-1} for the evergreen broadleaf forest, and 3.1±0.2 Mg ha^{-1} for the bamboo forest. These values were comparable to 8.2 Mg ha^{-1} for the forest floor of pines and 6.4 Mg ha^{-1} for the forest floor of oaks in Korea (Cha et al. 2019). N stocks on the forest floor were significantly lower in the bamboo forests than in the *C. obtusa* forests because of the lower amounts on the forest floor. In addition, the N stocks in the evergreen broadleaf (122±6 kg ha^{-1}) and bamboo (106±6 kg ha^{-1}) forests with low C:N ratios were lower than those in the *C. japonica* (160±18 kg ha^{-1}) and *C. obtusa* (169±21 kg ha^{-1}) forests. Spohn and Stendahl (2022) reported that the N stocks in the forest floor of Swedish forests are related to the mean annual temperature, which was attributed to N_2 fixation or the P-dependence of litter decomposition. Large P stocks in the *C. japonica* (10.8±0.9 kg ha^{-1}) and *C. obtusa* (13.4±1.3 kg ha^{-1}) forests could be due to slow litter decomposition at high C:N ratios (Manzoni et al. 2010) induced by different tree species (Spohn and Stendahl 2022).

Conclusion

The results of this study indicate that the stoichiometry and nutrient stocks of the forest floor may be related to the differences in litterfall returns and the litter decomposition process induced by taxonomic lineages, such as coniferous or broadleaf plants. The C, N, and P stocks by vegetation type were associated with the amount of forest floor and stoichiometric ratios determined by the nutrient concentrations in the forest floor. This study provides useful information to understand and predict C and nutrient dynamics in forest floor layer in Korean warm-termperatre forests.

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