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ORIGINAL RESEARCH

Correlation Between Coarse Wood Debris and Soil Different Chemical Properties of Three Forest Types in Northeast China

Kashif Khan[1,*], Imran Azeem[2], Lixin Chen[1], Changzhun Li[1], Meixue Qu[1], Yafei Wang[1]

[1]Key Laboratory of Sustainable Forest Ecosystem Management-Ministry of Education, Northeast Forestry University, Harbin 150040, China.

[2]Beijing Key Laboratory of Farmland Soil Pollution Prevention and Remediation and College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, PR China.

*Corresponding author:
kashifkhanses@gmail.com

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ABSTRACT: Coarse wood debris (CWD) is a critical component of the nitrogen and carbon pools in forest ecosystems. While CWD decomposition rates have been studied extensively across various ecosystems, the effects of CWD on soil properties and their interrelations remain unclear. This study aimed to measure the response of CWD to soil and their interrelations among three forest types: *Picea koraiensis-Abies nephrolepis-Pinus koraiensis forest* (PAPF), *Betula costata-Pinus koraiensis* forest (BPF), and *Tilia amurensis-Pinus koraiensis* forest (TPF). The results indicated that CWD carbon was positively correlated with soil pH (R^2=0.36). CWD nitrogen was positively correlated with urease activity, while negatively correlated with dehydrogenase activity. There was a consistent correlation between overall CWD and soil nutrient concentrations among the three forest types, although the pattern of these correlations varied among PAPF, BPF, and TPF. This highlights the need to explore attribute interrelations across different ecological gradients. Overall, CWD phosphorus (P) and carbon (C) were positively correlated with soil pH, while aluminum (Al) was negatively correlated. CWD nitrogen (N) was positively correlated with urease enzyme activity, whereas CWD carbon (C) and nitrogen (N) were negatively correlated with invertase and dehydrogenase enzymes, respectively. CWD sulfur (S) was positively correlated with soil sulfur, while CWD carbon (C), potassium (K), and magnesium (Mg) were negatively correlated with their respective soil counterparts. This study demonstrates that variations in soil nutrient concentrations and enzymatic activity are significantly influenced by decomposition levels.

KEYWORDS: Coarse wood debris, soil properties, nutrient cycling, enzymatic activity, forest ecosystems

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1. Introduction

Coarse wood debris (CWD) can form under competitive conditions among tree growth, natural deforestation in old age, natural interferences (e.g., fire, rain, lightning, snow, wind, insects, and invasion of fungi), and human intervention (tree hacking and logging) (Yuan et al., 2011). Within ecological systems, CWD plays an important role in production, carbon sequestration, nutrient recycling, community regeneration, and biodiversity (Ganjegunte et al., 2004; Gough et al., 2007; Janisch & Harmon, 2002; Wilcke et al., 2005; Woodall, Liknes, & management, 2008). Coarse wood debris can significantly contribute to carbon and nutrient activation in ecosystems (Rinne-Garmston et al., 2019). Through decomposition, carbon, nitrogen, phosphorus, potassium, calcium, magnesium, and manganese are stored in wood debris and released into ecosystems. In temperate forests, aboveground forest biomass contains 17% dead wood, which serves as a crucial nutrient source (Dar, Sundarapandian et al., 2015). Both CWD and fine dirt are vital components in forest carbon and nitrogen cycles (Bessaad et al., 2021). CWD can function as a site for nitrogen fixation, seed germination support, and water storage. CWD has been extensively studied for its significant role in forest carbon cycling (Keith et al., 2009; Merganičová et al., 2012). Respiratory carbon loss is a crucial process in CWD degradation (Jomura., 2008). For instance, Wu et al. (2019) demonstrated that up to 76% of all carbon was lost through respiration during the entire decomposition period of CWD logs in the tropics. Warner et al.)2017) estimated that 35% of total CO2 fluxes in CWD and dead stems occurred in a high-altitude forest in the USA. Global CWD stores about 36–72 Pg C, potentially disrupting total forest carbon frameworks (Sierra, 2006). CWD dispersal and quantity are influenced by tree mortality, decomposition rate, age, climate, tree species, site characteristics, and disturbance dynamics.

Dead wood gradually releases nutrients through decomposition, with amounts contingent on substrate, climatic conditions, and species (Jones et al., 2019; Ulyshen et al., 2017). Released nutrients can be retained in soil, available for microorganisms and plant growth (Lodge., 1994). The impact of wood decomposition on soil varies according to soil properties and nutritional status (Berg et al., 2000). Specifically, dead wood and nutrient storage contributions are particularly pronounced in Mediterranean pine forests, often located on poor soils with high nutrient demands. CWD is also considered an essential structural and functional element in various forest environments, enhancing local ecosystem diversity, spatial heterogeneity, and wildlife (Bunnell et al., 2010). Wood decomposition has been reported to stimulate microbial diversity and promote the growth of ectomycorrhizal fungi, indicators of nutrient-rich forest soils. Additionally, organic materials and nutrients present in wood enhance microbial activity, leading to increased nutrient cycling (Marañón-Jiménez et al., 2013).

CWD decomposition is a complex process influenced by various factors such as forest types, humidity, temperature, substrate quality, and decomposer types (Harmon et al., 2011). Measuring decay rates is challenging due to the slow pace of decomposition and physical fragmentation, often spanning decades or even centuries. Studies comparing CWD across decay classes have noted nutrient loss patterns; for instance, potassium (K) and magnesium (Mg) are lost relatively quickly, while calcium (Ca), nitrogen (N), and phosphorus (P) are retained during initial decay phases and released later (Jamieson et al., 2018). However, determining the precise age of CWD in each decay class remains a challenge, impacting the understanding of nutrient release timing. Although time series analysis can help differentiate CWD age, it may take decades, potentially missing key stages of nutrient import/export from CWD (Johnson et al., 2014).

CWD is a crucial component of forested ecosystems, providing structural habitat, serving as the primary energy source for saprophyte communities, and contributing significantly to long-term soil development.

This reciprocal relationship between soil and CWD is essential for sustaining soil fertility and supporting plant growth and ecosystem health.

Research indicates that interactions between soil carbon (C) and nitrogen (N) and the composition of the plant community are crucial for soil biochemistry and ecological function. CWD supplies C and essential nutrients for decomposer communities, influencing soil organic carbon dynamics and microbial processes. Understanding the relationship between aboveground and belowground systems is vital for forest ecosystems, which serve as significant C sinks. Plant and soil nitrogen availability interact, affecting ecosystem function as plant species influence N mineralization and nitrification rates (Neher, 1999). Further inquiry is needed to understand the drivers of the relationship between CWD and soil nitrogen cycling.

Therefore, the current study aims to comprehend the effects of CWD on soil systems. This research focuses on (1) the relationship between CWD and soil pH, C and N, and soil nutrients, and (2) the positive correlation between CWD and soil enzyme activity. The aim of our study is to clarify the relationship between CWD and soil characteristics in three different forests.

2. Materials and methods

2.1. Study Area

The study was conducted in the Liangshui National Nature Reserve (47°10′50″ N, 128°53′20″ E) in Heilongjiang Province, China. The reserve covers 12.14 km², with elevations from 300 to 707.4 meters above sea level and slopes of 10°–15°. It has a forest coverage of 96 percent and lies in a temperate continental monsoon climatic zone. The average temperature is −0.3 °C, with long, cold winters and a soil freeze depth of about 2 meters. Annual rainfall averages 680 mm over 120 days, with cumulative evaporation of about 800 mm. The area receives 43.5% daily light and 1,850 hours of sunlight annually.

2.2. Experiment 1

The experiment was conducted on three permanent plots of different sizes established in August 2017 in randomly selected forest types: *Picea koraiensis-Abies nephrolepis-Pinus koraiensis (PAPF), Betula costata-Pinus koraiensis (BPF), and Tilia amurensis-Pinus koraiensis (TPF)*. All samples were collected from *Pinus koraiensis* (PK) at various stages of decay. Wood debris was classified into decay stages based on morphology and hardness following field criteria. Decay stages for PK were recorded as follows: Stage I: Recently fallen logs with twigs and leaves, hard wood, Stage II: Logs with bark but no leaves, hard wood, Stage III: Partially present bark, semi-solid wood, Stage IV: No bark, partially soft wood, The fifth decay stage, characterized by soft, fragmented wood, was often indistinguishable and not considered in the study. Nutrient concentrations were calculated at different decay levels to assess changes.

2.3. Experiment 2

In October 2019, a factorial experiment was conducted on three permanent plots within randomly selected forests: *Picea koraiensis-Abies nephrolepis*-Pinus *koraiensis* (PAPF), *Betula costata-Pinus koraiensis* (BPF), and *Tilia amurensis-Pinus*

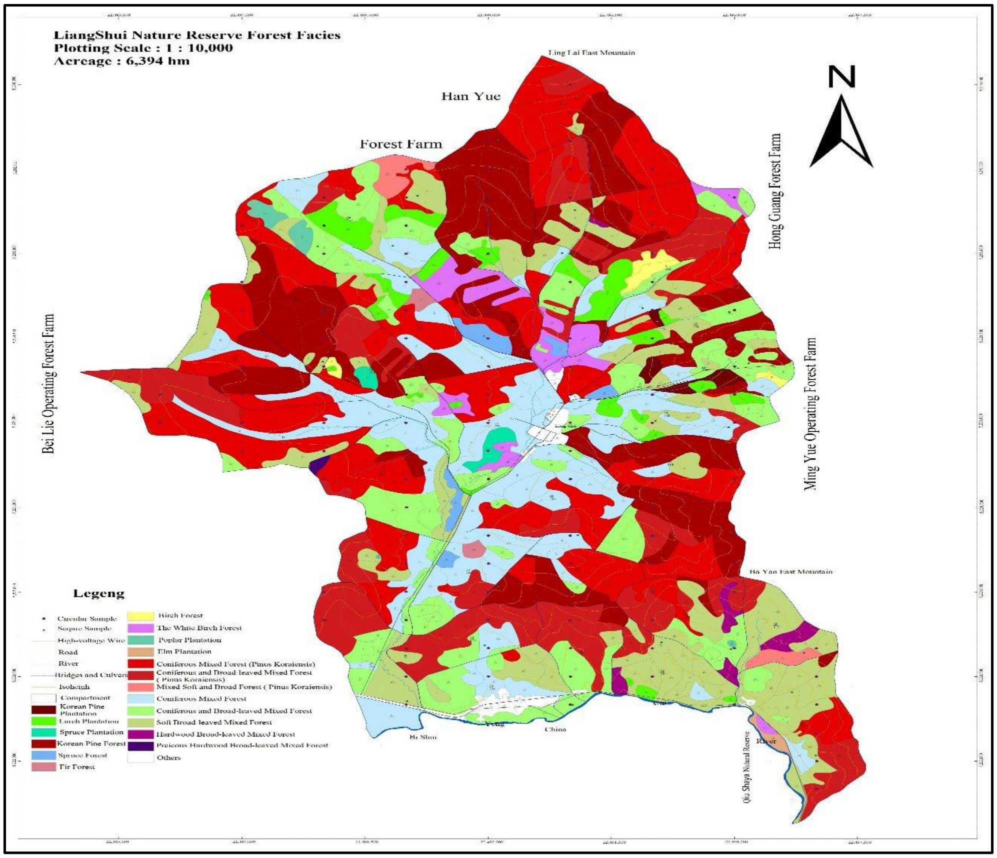

Figure 1. A map showing forest distribution in Liangshui National Nature Reserve, Northeast China. (Khan et al., 2022).

koraiensis (TPF). The plot sizes were 100 m × 120 m, 100 m × 110 m, and 100 m × 120 m, respectively. The study aimed to determine nutrient concentration changes at different decay levels in *Pinus koraiensis* (PK), the dominant tree species. Samples representing various decomposition stages were collected and classified using a decay class system based on morphology and hardness. Decay stages selected were: Class III: Partially present bark, semi-solid wood, Class IV: No bark, partially soft wood. These classes were identified through visual observation to meet the study objectives.

2.4. Sample Processing and Analysis of Nutrients

2.4.1 Sampling of coarse wood debris

For elemental determination of coarse wood debris (CWD), log samples approximately 10 cm in diameter were collected for each decay class of Pinus *koraiensis* (PK) in three forest types: *Picea koraiensis-Abies nephrolepis-Pinus koraiensis* forest (PAPF), *Betula costata-Pinus koraiensis* forest (BPF), and *Tilia amurensis-Pinus koraiensis* forest (TPF). Nutrient concentrations of CWD from PK at different decay levels in each forest type were determined and compared both within and between the different forest types. Five samples per decay class were collected from each forest type. All samples were labeled, placed in sealed plastic bags, transported to the laboratory, and stored in a refrigerator at

4°C until processing. To avoid contamination, samples were handled with nitrile gloves in both the field and the laboratory.

2.4.2. Sampling of Soil

In October 2019, soil samples were collected from lateral distances under decaying logs and 50 cm away from each decay class log. We used log samples of approximately 20–50 cm in diameter from the same dominant tree species, *Pinus koraiensis* (PK), in three forest types: Picea *koraiensis-Abies nephrolepis-Pinus koraiensis* forest (PAPF), *Betula costata-Pinus koraiensis* forest (BPF), and *Tilia amurensis-Pinus koraiensis* forest (TPF). Twenty logs were randomly selected in each forest type, with ten logs for each decay class III and IV. Five soil samples were taken from each log and pooled to create one composite soil sample, resulting in a total of 20 soil samples collected at a depth of 0–20 cm for each forest type. These samples were labeled, sealed in plastic bags, transported to the laboratory, and refrigerated at 4°C until processing. To avoid contamination, nitrile gloves were used when handling the samples.

2.5. Measurements and analysis

To determine nutrient concentrations in coarse wood debris (CWD), we collected log samples (~10 cm diameter) for each decay class of *Pinus koraiensis* (PK). The samples were carefully handled, stored, and transported to the laboratory. Soil particles were removed by brushing, and the samples were oven-dried at 65°C, then ground into powder for biochemical analysis. The ground samples were weighed and digested with a mixed acid (HNO_3 + $HClO_4$ in a 5:1 ratio). Nutrient concentrations of phosphorus (P), potassium (K), magnesium (Mg), sodium (Na), manganese (Mn), aluminum (Al), boron (B), iron (Fe), and zinc (Zn) were determined using an ICP-AES (Optima-8300 DV; PerkinElmer, Inc.). Total carbon (C) and nitrogen (N) were measured using a LECO C/N analyzer. Nutrient concentrations for each decay class of PK were compared, and the experiment was replicated three times for each decay class.

The soil samples were divided for different analysis. One set was air-dried, ground, and sieved through a 2-mm mesh to determine exchangeable cations, NH_4^+-N, and NO_3^--N. A second set was processed through a 0.5-mm sieve for phosphorus and soil pH measurement. A third set was oven-dried and passed through a 0.25-mm sieve to determine total nitrogen and soil organic carbon. Fresh soil was stored at 4°C to evaluate enzymatic activity. Detailed procedures for measuring soil organic carbon (SOC), total N, NH_4^+-N (ammonium), NO_3–-N (nitrate), exchangeable cations (Ca_2^+, Mg_2^+, Mn_2^+), phosphorus (P), sulfur (S), potassium (K), and the activities of urease, invertase, polyphenol oxidase, dehydrogenase, and acid phosphatase are provided in our previous study (Khan et al., 2022).

2.6. Statistical Analysis

Both soil and coarse wood debris data were analyzed using two-way ANOVA. To assess significant differences among various forest types and decay classes, Tukey's HSD test was employed. Redundancy analysis (RDA) was conducted using the vegan package in R v. 3.6.1. Pearson's correlation coefficients were determined with the corrplot package in R v. 3.6.1. All statistical analyses were carried out using SPSS v. 25, and SigmaPlot v. 12.4 (Systat Software Inc., San Jose, CA, USA) was utilized for creating graphical representations. The results are expressed as mean ± standard error (SE).

3. Results

3.1. Nutrient concentration across different decay classes and forest types

As published in our previous study (Khan et al., 2021), results indicated that concentrations of N, P, Mg, Mn, Na, Zn, S, Al, and Fe generally increased with the level of decay across all three forest types, except for K and B in PAPF. The highest concentrations of N, P, B, Mg, K, C, Zn, and Mn in coarse wood debris (CWD) were found in BPF, while the highest concentrations of Fe and S were observed in PAPF and TPF, respectively. C content did not show significant differences between decay classes across the forest types. The C ratio significantly decreased with increasing decay levels in all forest types, and decay rates were significantly correlated with N concentration and the C ratio across all forest types.

3.2.Changes in forest soil bio-geochemcal traits under decay classes and forest types

As previously published in our study (Khan et al., 2022), the results indicated that soil organic carbon (OC), nitrogen (N), soil pH, other nutrients, and enzymatic activity were significantly influenced by forest type, decay class, and proximity to decaying logs across the three forests. In PAPF forest, decay class IV CWD showed the highest levels of OC (64.7 mg g^{-1}), N (6.9 mg g^{-1}), and enzymatic activity, with minimal impact from distance to decaying logs across all forests. A lower soil pH value of 3.8 was noted near decay class IV deadwood. CWD plays a vital role in enhancing carbon and nutrient budgets and boosting soil enzymatic activity in forest ecosystems. This research concludes that CWD is essential for nutrient cycling, contributing to the spatial heterogeneity of enzymatic activity, carbon, and nutrient turnover on the forest floor.

3.3. Correlations analysis

In the present study, we used our previously published data from Khan et al. (2021) and Khan et al. (2022) to evaluate the correlations between coarse wood debris (CWD) and various soil chemical properties, enzymes activities, etc.

3.3.1 Correlation among coarse wood debris and soil different chemical properties

We examined the correlations of CWD nitrogen (N) with urease and dehydrogenase enzymes, and CWD carbon (C) with invertase enzymes (Figure 2). The results indicated that CWD was positively correlated with the urease enzyme and negatively correlated with the dehydrogenase enzyme (Figure 2). Conversely, CWD C was negatively correlated with soil invertase enzyme activity (Figure. 2), with an R^2 value of 0.53.

CWD C was strongly negatively correlated with soil C (Figure 3A), with an R^2 value of 0.34. CWD N and phosphorus (P) were significantly correlated with soil N and P, respectively (Figure 3B and C). CWD potassium (K) was negatively correlated with soil K, with an R^2 value of 0.62. On the other hand, CWD sulfur (S) showed a weak correlation with soil S (R^2 = 0.08) . Lastly, CWD magnesium (Mg) was negatively correlated with soil Mg, with an R² value of 0.17.

3.3.2 Correlations between soil and coarse wood debris properties across three different temperate forests types

The trait interrelations between soil properties and coarse wood debris (CWD) revealed several significant correlations (Figure 4). Soil carbon (C) was positively correlated with CWD sulfur (S) and negatively with CWD *Cin Betula costata-Pinus koraiensis* forest (BPF) and *Picea koraiensis-Abies nephrolepis-Pinus koraiensis* forest (PAPF). Additionally, soil C was positively correlated with CWD phosphorus (P) in PAPF and *Tilia amurensis-Pinus koraiensis* forest (TPF) and negatively with CWD S in BPF but positively in PAPF.

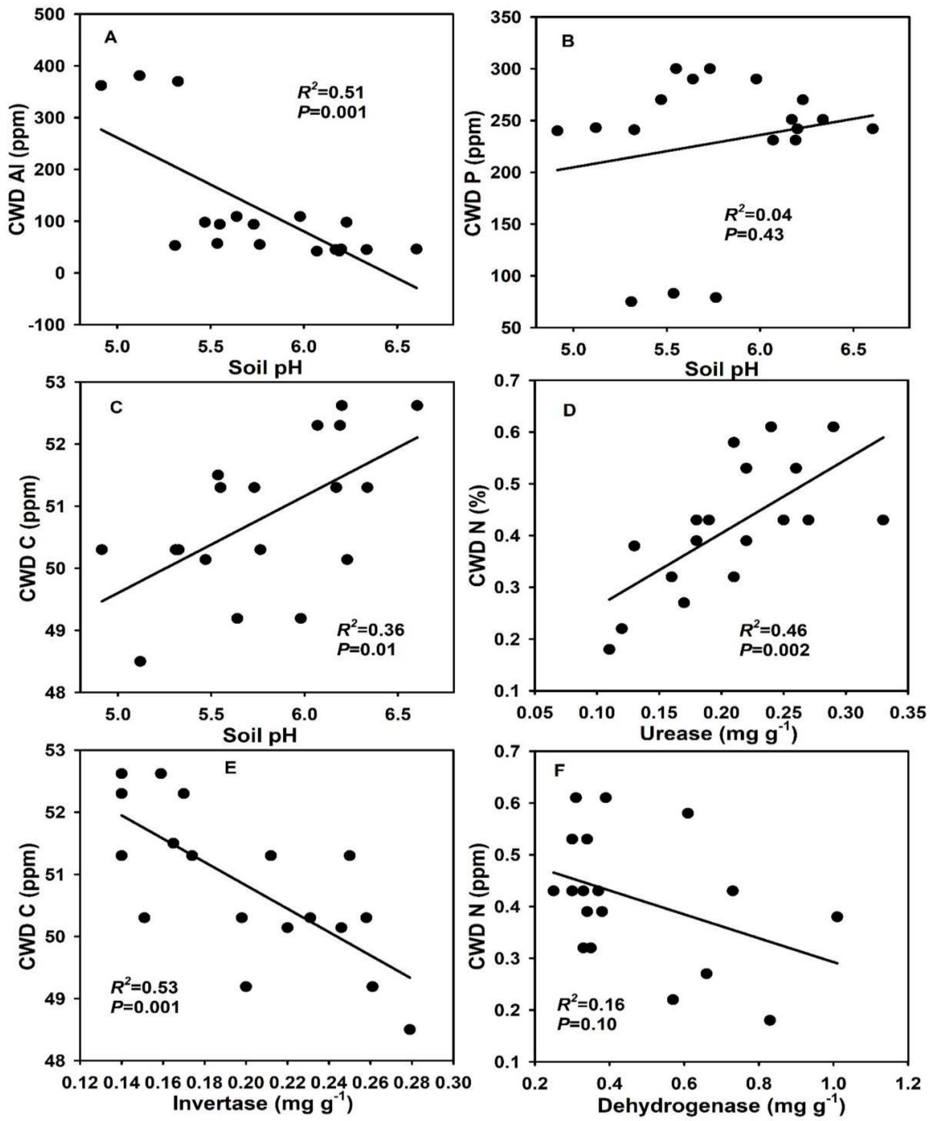

Figure 2. Correlation of coarse wood debris with different chemical properties. Note: CWMD-coarse wood debris, C-carbon, N-nitrogen, P-phosphorous, AI-aluminum.

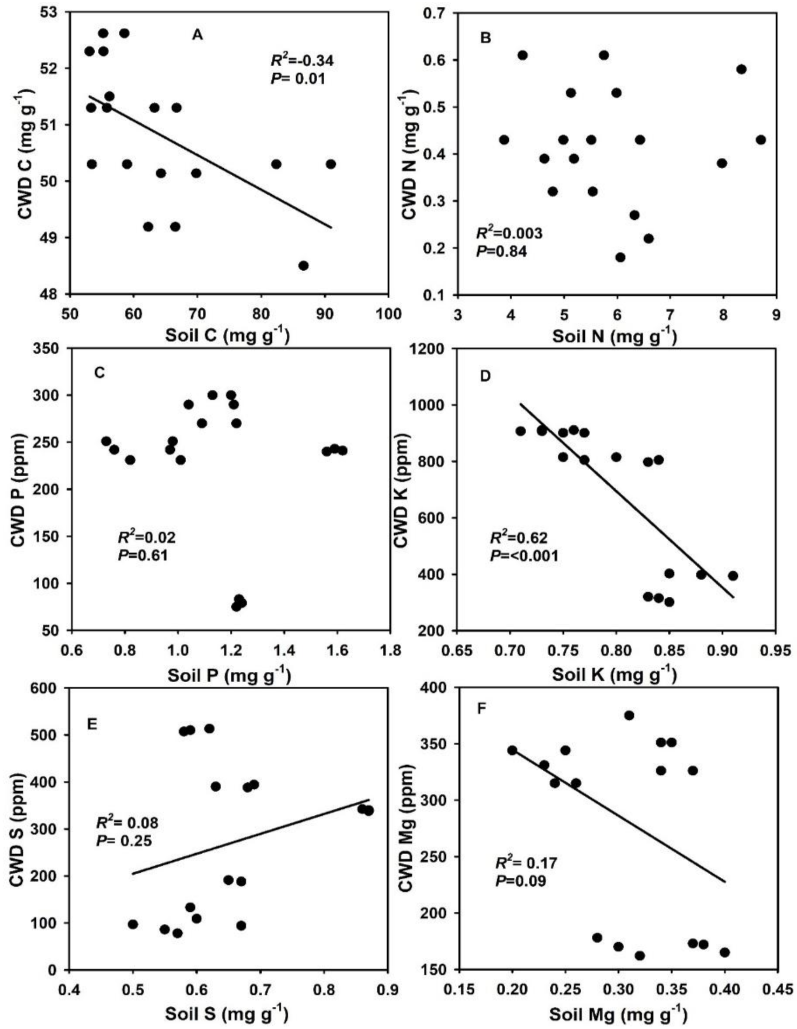

Figure 3. Correlation of coarse wood debris with different chemical properties.

Soil nitrogen (N) showed a positive correlation with CWD copper (Cu) in PAPF and a negative correlation in TPF. It was also negatively correlated with CWD potassium (K) and CWD S in BPF and positively correlated in PAPF. The soil C ratio was positively correlated with CWD N, P, aluminum (Al), iron (Fe), sodium (Na), S, and manganese (Mn) in PAPF, and negatively correlated with the Cratio. Soil ammonium (NH4) was positively correlated with CWD N in BPF and negatively with the CWD C ratio, but positively with P and Al in BPF and PAPF. Soil nitrate (NO3) was positively correlated with CWD N and negatively with the CWD C ratio in *Betula costata-Pinus koraiensis* forest (BAF) and PAPF. NO3 was negatively correlated with CWD S in BAF, but positively in PAPF, and positively correlated with CWD zinc (Zn) in TPF. Soil pH was negatively correlated with CWD P, Al, Fe, Zn, and Na, while positively correlated with CWD K and Mn in TPF. Soil phosphorus (P) was positively correlated with CWD N and Zn in PAPF and with CWD Mn in BAF and PAPF, but negatively in TPF. Soil potassium (K) was positively correlated with CWD Al, Fe, and Mn, and negatively with CWD K and S in BPF. Soil sulfur (S) was negatively correlated with CWD K in BPF and TPF but positively in PAPF. Soil magnesium (Mg) was correlated with CWD P in BPF and PAPF, negatively correlated with CWD K in BPF and TPF but positively in PAPF. Soil calcium (Ca) was negatively correlated with CWD S in BPF but positively in PAPF. Soil manganese (Mn) was negatively correlated with CWD K in BPF and TPF but positively in PAPF. Soil phosphatase was positively correlated with CWD Fe and Zn but negatively with CWD K and Mn in TPF. Overall, the correlation between soil properties and CWD properties was more consistent in PAPF compared to the other forest types.

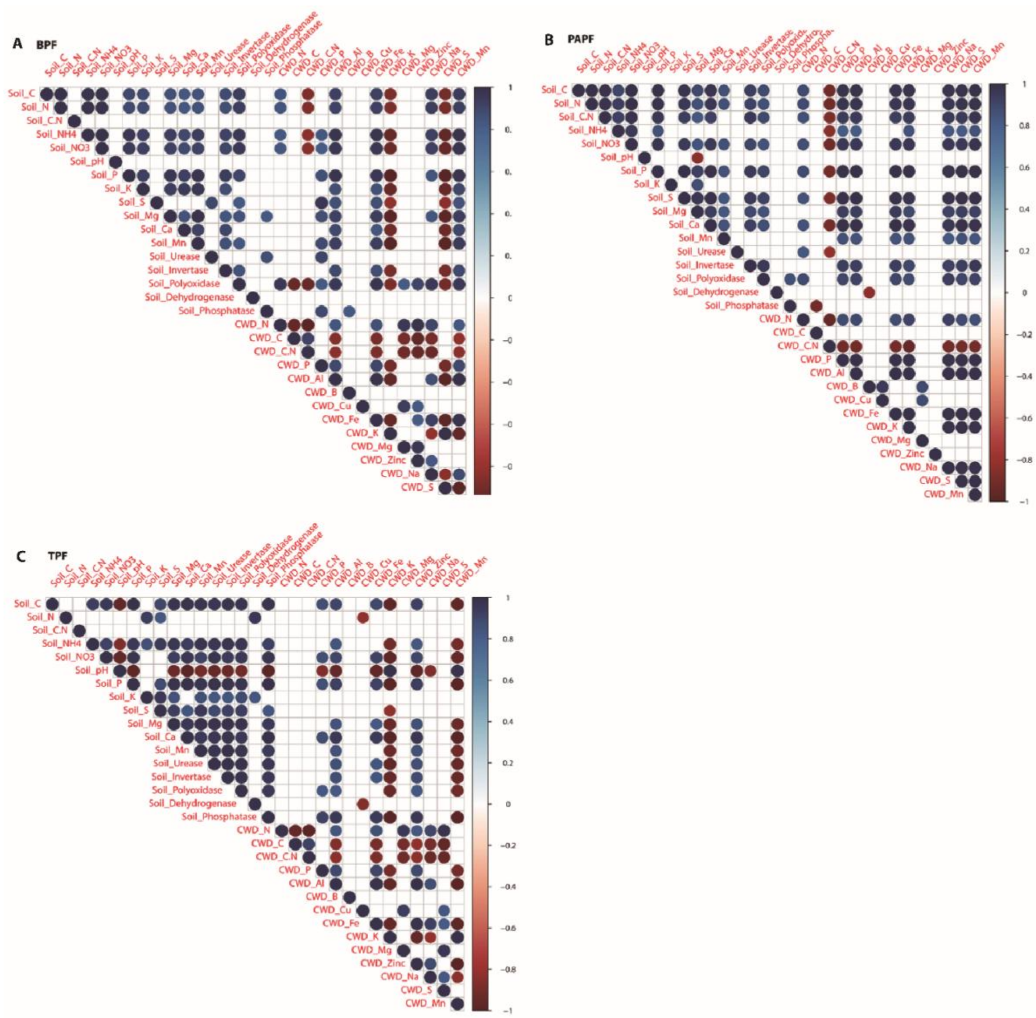

Figure 4. Pearson's correlation of soil properties and enzymatic activities of the dominant tree species (Pinus koraiensis, PK) between in Picea koraiensis-Abies nephrolepis-Pinus koraiensis forest (PAPF), *Betula costata-Pinus koraiensis* forest (BPF) and in Tilia amurensis-Pinus koraiensis forest (TPF) in northeastern China. The significant ($p < 0.05$) positive (blue color) or negative (red color) correlations are indicated by colors and circle sizes, while not significant correlations are omitted.

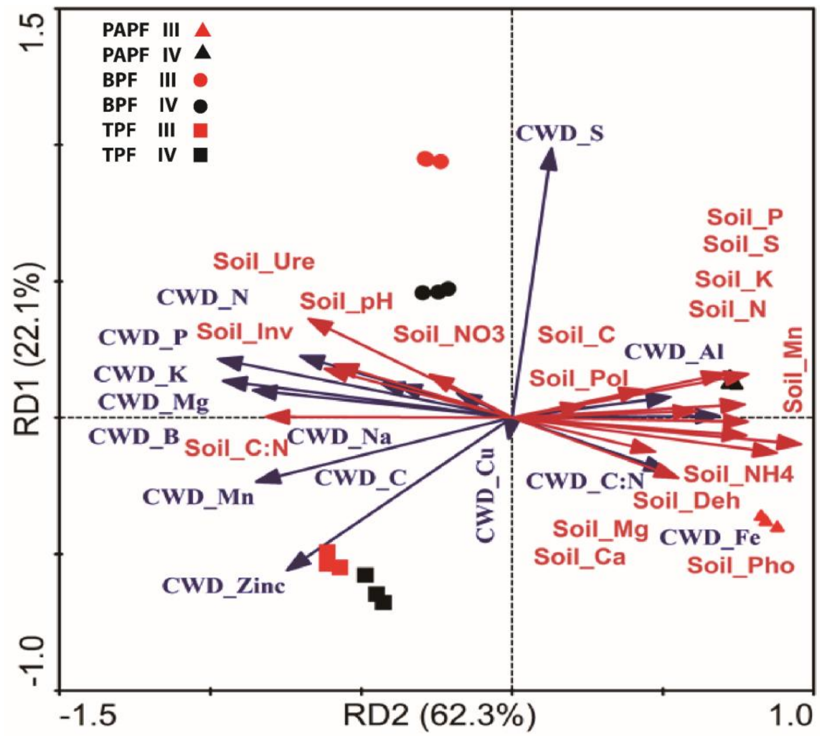

Figure 5. Redundancy Analysis of Nutritional Status Across Decay Classes in Different Forest Types of Northeastern China: Picea koraiensis-Abies nephrolepis-Pinus koraiensis (PAPF), *Betula costata-Pinus koraiensis* (BPF), and Tilia amurensis-Pinus koraiensis (TPF). Note: Al: aluminum; Zn: zinc; Fe: iron; N: nitrogen; P: phosphorus; Na: sodium; Mn: manganese; Cu: copper; B: boron; Mg: magnesium; K: potassium; C: carbon; S: sulfur; SOC: soil organic carbon; ST: soil temperature; TN: soil total nitrogen; SM: soil moisture; pH: soil pH; NH_4: ammonium; NH_3: ammonia.

3.3.3. Redundancy analysis

Redundancy analysis (RDA) was used to evaluate the interrelations between soil nutritional status and decay classes (Figure 5). The first and second RDA axes (RDA1 and RDA2) accounted for 62.3% and 22.1% of the total variation, respectively. CWD aluminum (Al), carbon-to-nitrogen ratio (C/N), and iron (Fe) had a strong positive impact on soil sulfur (S), phosphorus (P), potassium (K), nitrogen (N), ammonium (NH_4^+), calcium (Ca), magnesium (Mg), dehydrogenase, and phosphatase, while exerting a strong negative impact on urease, pH, and nitrate (NO_3^-). Conversely, CWD nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), boron (B), manganese (Mn), sodium (Na), carbon (C), and zinc (Zn) had a strong positive impact on soil urease, pH, and NO3-, while negatively impacting soil phosphorus (P), sulfur (S), potassium (K), nitrogen (N), carbon (C), calcium (Ca), magnesium (Mg), and manganese (Mn) (Figure 5).

4. Discussion

Decomposition of wood is essential for carbon dynamics and nutrient cycling in forest ecosystems (Rahman, et al., 2013; van der Wal, et al., 2013). It is a complex ecological process regulated by various factors: climate, substrate quality (tree species), and the abundance, composition, and activity of decomposer communities (Weedon et al., 2009). Deadwood decomposition occurs through fragmentation, dissolution, and respiration (Harmon, 1986). During decomposition, carbon (C) can be transferred to the atmosphere as CO_2 or added to soil C stocks. Highly decomposed wood significantly impacts soil, releasing more ions to the surface soil horizons compared to less decayed wood (Bade et al., 2015). In this study, we found a positive correlation between CWD and soil properties (Figures 1 and 2). Nutrient concentrations generally increased with advancing decay class, a pattern frequently observed in other studies (Khan et al., 2021). This may be due to mass loss, nutrient concentration, rainfall, and root colonization (Osman, 2013). The most plausible explanation is the presence of basidiomycetes within the log itself (Bunnell., 2014).

Soil pH is affected by CWD and its decay classes, though the exact mechanism of acidification remains unclear. Our study revealed that the base cation Al was moderately negatively correlated with soil pH. High concentrations of Al in CWD reduce soil pH, making it more acidic, likely due to the retention of base cations by CWD. Our results align with Iraci (2012), who stated that the retention of base cations can result in less leaching, thereby reducing soil pH (Figure 1A). Research by Dhiedt et al. (2019) also observed an increase in soil pH and a decrease in Al concentration near CWD (Dhiedt et al., 2019). Another possible explanation is that the composition of wood and the organisms responsible for decay differ. Softwood species are more associated with brown-rot fungi, which produce more organic acids, causing a decrease in pH, in contrast to hardwood species where white-rot fungi are predominant (Ray et al., 2010).

In our study, a correlation between CWD carbon (C) and soil pH was also observed, with an R value of 0.36, indicating a moderate positive correlation. A high quantity of CWD C slightly increased soil pH. Some studies support this finding. For instance, Hart et al. (1994) and Magill et al. (2000) observed that higher C concentrations underneath CWD cause high nitrogen (N) immobilization, reducing the negative impact of N deposition and leading to higher pH. CWD releases substances that affect soil chemical properties and enzyme activities, thereby altering the soil's nutrient status. Decomposition can cause variations in N, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents in the soil (Brais, 2005; Hua, 1992).

We found higher concentrations of N and P as the decay class advanced, similar to results by Kooch et al. (2017). According to Holub, et al. (2001), nutrient concentrations increase due to mass loss, microbial respiration, and leaching of organic matter. The accumulation of N in logs is partly facilitated by nitrogen-fixing bacteria that colonize decaying wood (Johnston et al., 2017), but primarily by the transfer of N from soil-foraging fungi to wood-decaying fungi (Filipiak, 2018). Mäkipää et al. (2017) found that cord-forming fungi can transport P to logs over large distances.

Soil microbial respiration is a major process that controls carbon (C) loss from terrestrial ecosystems (Walker et al., 2018). According to Kooch et al., (2019), soil total nitrogen (N) content significantly affects the decomposition of plant litter, and the litter decomposition rate is a major source of soil CO_2 emissions. Maron et al. (2018) reported that soil N content promotes the release of CO_2 from the soil. Mori et al. (2018) stated that increases in soil N and phosphorus (P) improve microbial respiration. Favorable soil conditions, such as higher pH, N, and available nutrients, enhance the activities of soil organisms, including earthworms and nematodes (Kooch et al., 2017).

The mineralization rate of soil N results from forest management practices under different canopy compositions (Tarus, 2020). N mineralization generally decreases when soil pH decreases (Qi et al., 2021). The relationships between plant community composition and soil C and N are essential to ecological function and soil biogeochemistry. Carbon allocation by plants plays an important role in soil C dynamics, but it is not clear how future changes in plant allocation will affect soil C stocks (Jaman et al., 2021). The mechanisms through which plant composition and diversity affect soil C dynamics in peatlands remain largely unexplored. Understanding the relationship between aboveground and belowground systems is particularly important in boreal peatlands, which are significant C sinks (Palozzi et al., 2017).

Interactions between plants and soil N availability are integral to the influence of plant diversity on ecosystem function. Plant species composition is tightly linked to soil N availability, as plant species have the potential to regulate N mineralization and nitrification (Matson et al., 2002). Some studies have found that greater plant diversity increases soil N availability because plant species richness positively affects soil N transformation and nitrification (Lamb, et al., 2011). However, other studies have shown that plant diversity decreases soil N availability (Bedford et al., 1999).

Recent research indicates that climate alone is insufficient to predict wood decomposition rates at regional scales. Instead, local-scale factors play a more crucial role in explaining most of the variation (Bradford et al., 2014). In natural conditions, fungi are the primary decomposers of deadwood. With their ability to utilize a range of secreted oxidoreductases and hydrolases, they are uniquely capable of decomposing lignin (Stokland et al., 2004). Microorganisms are essential agents of decomposition, with fungi being particularly significant due to their enzyme production capabilities and the ability to access new substrates through hyphae (Bani et al., 2018). Enzymes are fundamental for microorganisms to decompose organic matter and can indicate the nutrient status of the environment (Sinsabaugh et al., 2008). Our findings align with previous research, showing a positive correlation between wood physicochemical properties—such as decay stage, density, C ratio, and macronutrients like C, N, and P—and the structure of wood-inhabiting fungal communities (Rajala et al., 2012). This can be attributed to the presence of fungal communities across wide geographical distances, with priority effects and various biotic and abiotic factors determining the community in each log (Fukasawa & Management, 2015; Hiscox et al., 2016), and the successional changes that occur during wood decay (Hoppe et al., 2016).

In another study, it was observed that nitrogen addition accelerates urease activity (Bachmeier et al., 2002), likely due to the varied effects of nitrogen addition depending on the types and levels of different microorganism groups, which may secrete different enzymes in soils (Ahmad et al., 2023; Ahmad et al., 2022). Soil biological processes are regulated by soil microbial biomass, which produces enzymes that impact nutrient levels and availability (Dhandapani et al., 2020). High levels of organic carbon and nutrients under coarse woody debris (CWD) increase soil microbial biomass. However, previous studies have shown that urease activity decreases in the presence of stumps (Wang et al., 2012).

Our study revealed a moderately positive correlation (R= 0.46) between CWD nitrogen percentage and urease activity. Conversely, CWD carbon and invertase enzyme were negatively correlated (R = 0.53) (Fig. 1F). Previous research indicates that the presence of CWD leads to increased invertase and acid phosphatase activity. The negative correlation between CWD carbon and invertase enzyme is due to the conversion of CWD carbon into the soil. The more organic carbon present in soil, the higher the invertase activity observed. Literature mainly discusses indirect relevance concerning the presence of stumps on soil enzyme activity without direct effects being stated (Wang et al., 2012). The correlation is not completely linear, indicating that CWD carbon amounts are not solely dependent on invertase quantity. This may be because soil enzymes are produced by organisms utilizing organic matter from roots and residues (Sterilized et al., 2000). Previous studies suggest that the increase in enzyme activity is due to stumps being sources of labile carbon and other nutrients. The extractable organic carbon was high in CWD soil, indicating high amounts of carbon.

Similar to our results, Spears et al. (2003), Hafner et al. (2005), and Metzger et al. (2008) confirmed the leaching of labile carbon from CWD, thus reducing CWD carbon. Another study found a significant positive correlation between invertase and urease activity in relation to total nitrogen and organic carbon, reflecting nitrogen and organic matter decomposition in the soil (Wang et al., 2020).

The decomposition of CWD significantly influences soil chemical elements, as observed in our study. This is consistent with findings by Ge et al. (2013), although some studies report non-significant effects of CWD decay on soil chemical properties (Laiho et al., 2004; Spears et al., 2003; Wilcke et al., 2005). For example, studies have shown that potassium (K) concentration in pine CWD decreases over time (Bilous et al., 2019), with nitrogen (N), phosphorus (P), and sulfur (S) concentrations peaking in 36-year-old decomposed spruce. In our study, K concentration in CWD decreased and subsequently increased in the soil, revealing a moderately strong negative correlation (R=0.62, Fig 2D). This is likely due to K's high mobility and tendency to leach out early in the decay process (Holub et al., 2001; Means et al., 1992).

Contrarily, other research indicated increased K content in CWD of boreal forests as decay progresses, possibly due to differences in tree species and decomposition factors (Krankina et al., 2004). Kavanagh (2017) highlighted K's role as a crucial cofactor for enzymatic activities, suggesting that increased fungal decomposition in CWD enhances K leaching into the soil. Additional studies support our findings, attributing the decrease in CWD K to leaching (Khan et al., 2021). In our research, CWD contents of N and P did not correlate with soil contents over the decay period, a finding supported by previous studies showing inconsistent results. For instance, Yuan et al. (2017) noted significant variations in N and P contents over time, dependent on tree species, with greater K release observed in *Q. aliena var. acuteserrata* compared to *P. armandii*.

Our results indicated a weak negative correlation (R=0.34) between CWD C content and soil C content. Although Yuan et al. (2017) found that soil C content significantly increased as CWD C content decreased, we observed a less pronounced correlation. They also reported considerable fluctuations in soil N, P, K, Ca, and Mg contents relative to CWD quantities, attributing these variations to environmental factors. Other studies suggest that phosphorus tends to be retained in CWD over time due to its resistance to leaching (Minghe, Guoyi, Deqiang, Lili, & Botany, 2006). Our study found no correlation (R=0.02) between CWD P and soil P, likely for the same reason (Figure 2C).

Previous research has shown that enzyme activity increases because stumps serve as sources of labile C and other nutrients. The high extractable organic C in CWD soil suggests substantial amounts of C. Metzger et al. (2008) confirmed the leaching of labile C from CWD, reducing CWD C content. Another study found a significant positive correlation between invertase and urease activity with total nitrogen and organic carbon, reflecting the decomposition of nitrogen and organic matter in the soil (H. Wang et al., 2020).

5. Conclusion

There was a consistent correlation in overall CWD and soil nutrient concentrations among the three forest types (PAPF, BPF, and TPF). However, the pattern of these correlations differed among the forest types. This highlights the need for further exploration of attribute interrelations across varying ecological gradients. The results reveal that the relationship between CWD and soil properties depends on plant species and decay classes. We observed that overall CWD phosphorus (P) and carbon (C) were positively correlated with soil pH, while aluminum (Al) was negatively correlated. CWD nitrogen (N) was positively correlated with urease enzyme activity, whereas CWD carbon (C) and nitrogen (N) were negatively correlated with invertase and dehydrogenase enzymes, respectively. CWD sulfur (S) was positively correlated with soil sulfur, while CWD carbon (C), potassium (K), and magnesium (Mg) were negatively correlated with their respective soil counterparts. This study indicates that variations in soil nutrient concentrations and enzymatic activity are significantly affected by decomposition levels. Future research is needed to better understand the relationship between CWD and other ecological aspects at different decomposition levels in various climatic regimes.

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REFERENCES

Ahmad, R., Gao, J., Li, W., Zhang, Y., Gao, Z., Khan, A., ... & Fahad, S. Response of soil nutrients, enzyme activities, and fungal communities to biochar availability in the rhizosphere of mountainous apple trees. Plant and Soil. (2023). 489(1), 277-293. https://doi.org/10.1007/s11104-023-06016-4

Ahmad, R., Gao, J., Gao, Z., Khan, A., Ali, I., & Fahad, S. Influence of biochar on soil nutrients and associated Rhizobacterial communities of mountainous apple trees in northern loess plateau China. Microorganisms. (2022). 10(10), 2078. https://doi.org/10.3390/microorganisms10102078

Bachmeier, K. L., Williams, A. E., Warmington, J. R., & Bang, S. S. Urease activity in microbiologically-induced calcite precipitation. Journal of biotechnology. (2002). 93(2), 171-181. https://doi.org/10.1016/S0168-1656(01)00393-5

Bade, C., Jacob, M., Leuschner, C., & Hauck, M. Chemical properties of decaying wood in an old-growth spruce forest and effects on soil chemistry. Biogeochemistry. (2015). 122, 1-13. https://doi.org/10.1007/s10533-014-0015-x

Bani, A., Pioli, S., Ventura, M., Panzacchi, P., Borruso, L., Tognetti, R., & Brusetti, L. The role of microbial community in the decomposition of leaf litter and deadwood. Applied soil ecology. (2018). 126, 75-84. https://doi.org/10.1016/j.apsoil.2018.02.017

Bedford, B. L., Walbridge, M. R., & Aldous, A. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology. (1999). 80(7), 2151-2169. https://doi.org/10.1890/0012-9658(1999)080[2151:PINAAP]2.0.CO;2

Berg, B. Litter decomposition and organic matter turnover in northern forest soils. Forest ecology and Management. (2000). 133(1-2), 13-22. https://doi.org/10.1016/S0378-1127(99)00294-7

Bessaad, A., Bilger, I., & Korboulewsky, N. Assessing biomass removal and woody debris in whole-tree harvesting system: Are the recommended levels of residues ensured?. Forests. (2021). 12(6), 807. https://doi.org/10.3390/f12060807

Bilous, A., Matsala, M., Radchenko, V., Matiashuk, R., Boiko, S., & Bilous, S. Coarse woody debris in mature oak stands of Ukraine: carbon stock and decomposition features. Forestry Ideas. (2019). 25(1), 196-219.

Bradford, M. A., Warren II, R. J., Baldrian, P., Crowther, T. W., Maynard, D. S., Oldfield, E. E., ... & King, J. R. Climate fails to predict wood decomposition at regional scales. Nature Climate Change. (2014). 4(7), 625-630. https://doi.org/10.1038/nclimate2251

Brais, S., Sadi, F., Bergeron, Y., & Grenier, Y. (2005). Coarse woody debris dynamics in a post-fire jack pine chronosequence and its relation with site productivity. Forest Ecology and Management. (2005). 220 (1-3), 216-226. https://doi.org/10.1016/j.foreco.2005.08.013

Bunnell, F. L., & Houde, I. Down wood and biodiversity—implications to forest practices. Environmental Reviews. (2010). 18(NA), 397-421. https://doi.org/10.1139/A10-019

Bunnell, F. L., Kremsater, L. L., & Moy, A. Coarse filter assessment of contribution of dying and dead wood to sustaining biodiversity on TFL 48 Progress Report. (2014).

Dar, J. A., & Sundarapandian, S. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environmental monitoring and assessment. (2015). 187, 1-17. https://doi.org/10.1007/s10661-015-4299-7

Dhandapani, S., Ritz, K., Evers, S., Cooper, H., Tonks, A., & Sjögersten, S. Land-use changes associated with oil palm plantations impact PLFA microbial phenotypic community structure throughout the depth of tropical peats. Wetlands. (2020). 40(6), 2351-2366. https://doi.org/10.1007/s13157-020-01342-0

Dhiedt, E., De Keersmaeker, L., Vandekerkhove, K., & Verheyen, K. Effects of decomposing beech (Fagus sylvatica) logs on the chemistry of acidified sand and loam soils in two forest reserves in Flanders (northern Belgium). Forest ecology and management. (2019). 445, 70-81 https://doi.org/10.1016/j.foreco.2019.05.006

Filipiak, M. Nutrient dynamics in decomposing dead wood in the context of wood eater requirements: The ecological stoichiometry of saproxylophagous insects Saproxylic Insects (pp. 429-469): Springer. (2018). https://doi.org/10.1007/978-3-319-75937-1_13

Fukasawa, Y. The geographical gradient of pine log decomposition in Japan. Forest Ecology and Management. (2015). 349, 29-35 https://doi.org/10.1016/j.foreco.2015.04.010

Ganjegunte, G. K., Condron, L. M., Clinton, P. W., Davis, M. R., & Mahieu, N. (2004). Decomposition and nutrient release from radiata pine (Pinus radiata) coarse woody debris. Forest Ecology and Management, 187(2-3), 197-211. https://doi.org/10.1016/S0378-1127(03)00332-3

Ge, X., Xiao, W., Zeng, L., Huang, Z., Lei, J., & Li, M. H. The link between litterfall, substrate quality, decomposition rate, and soil nutrient supply in 30-year-old pinus massoniana forests in the three gorges reservoir area, China. Soil science. (2013). 178(8), 442-45. https://doi.org/10.1097/SS.0000000000000004

Gonzalez-Polo, M., Fernández-Souto, A., & Austin, A. T. Coarse woody debris stimulates soil enzymatic activity and litter decomposition in an old-growth temperate forest of Patagonia, Argentina. Ecosystems. (2013). 16, 1025-1038. https://doi.org/10.1007/s10021-013-9665-0

Gough, C. M., Vogel, C. S., Kazanski, C., Nagel, L., Flower, C. E., & Curtis, P. S. Coarse woody debris and the carbon balance of a north temperate forest. Forest Ecology and Management. (2007). 244(1-3), 60-67. https://doi.org/10.1016/j.foreco.2007.03.039

Hafner, S. D., Groffman, P. M., & Mitchell, M. J. Leaching of dissolved organic carbon, dissolved organic nitrogen, and other solutes from coarse woody debris and litter in a mixed forest in New York State. Biogeochemistry. (2005). 74, 257-282. https://doi.org/10.1007/s10533-004-4722-6

Harmon, M. E., & Chen, H. JF Franklin, FJ Swanson, P. Sollins, SV Gregory, JD Lattin, NH Anderson, SP Cline, NG Aumen, JR Sedell, GW Lienkaemper, K. Cromack, Jr., and KW Cummins. (1986). 133-302. https://doi.org/10.1016/S0065-2504(08)60121-X

Harmon, M. E., Bond-Lamberty, B., Tang, J., & Vargas, R. Heterotrophic respiration in disturbed forests: A review with examples from North America. Journal of Geophysical Research: Biogeosciences. (2011). 116(G4). https://doi.org/10.1029/2010JG001495

Hart, S. C., Nason, G. E., Myrold, D. D., & Perry, D. A. Dynamics of gross nitrogen transformations in an old-growth forest: The carbon connection. Ecology. (1994). 75(4), 880-891. https://doi.org/10.2307/1939413

Hiscox, J., Savoury, M., Johnston, S. R., Parfitt, D., Müller, C. T., Rogers, H. J., & Boddy, L. Location, location, location: priority effects in wood decay communities may vary between sites. Environmental Microbiology. (2016). 18(6), 1954-1969. https://doi.org/10.1111/1462-2920.13141

Holub, S. M., Spears, J. D., & Lajtha, K. A reanalysis of nutrient dynamics in coniferous coarse woody debris. Canadian Journal of Forest Research. (2001). 31(11), 1894-1902. https://doi.org/10.1139/x01-125

Hoppe, B., Purahong, W., Wubet, T., Kahl, T., Bauhus, J., Arnstadt, T., ... & Krüger, D. (2016). Linking molecular deadwood-inhabiting fungal diversity and community dynamics to ecosystem functions and processes in Central European forests. Fungal Diversity, 77, 367-379. https://doi.org/10.1007/s13225-015-0341-x

Hua, C., & Harmon, M. E. (1992). A study on dynamics of coarse woody debris in temperate forest ecosystems. Chinese Journal of Applied Ecology, 3.

Iraci, J. M. (2012). Nutrient and biomass contributions of downed woody debris in boreal mixedwood forests of northeastern Ontario. University of Toronto (Canada).

Jaman, M. S., Muraina, T. O., Dam, Q., Zhang, X., Jamil, M., Bhattarai, S., & Islam, F. (2021). Effects of single and mixed plant types on soil carbon and nitrogen dynamics in homestead agroforestry systems in Northern Bangladesh. Agriculture, Ecosystems & Environment, 315, 107434. https://doi.org/10.1016/j.agee.2021.107434

Jamieson, T. J., Watmough, S. A., & Eimers, M. C. Increase in woody debris nutrient pools in stream channels following selection harvesting in a northern hardwood forest. Forest ecology and management. (2018). 409, 8-18. https://doi.org/10.1016/j.foreco.2017.10.057

Janisch, J. E., & Harmon, M. E. Successional changes in live and dead wood carbon stores: implications for net ecosystem productivity. Tree physiology. (2002). 22(2-3), 77-89. https://doi.org/10.1093/treephys/22.2-3.77

Johnson, C. E., Siccama, T. G., Denny, E. G., Koppers, M. M., & Vogt, D. J. In situ decomposition of northern hardwood tree boles: decay rates and nutrient dynamics in wood and bark. Canadian Journal of Forest Research. (2014). 44(12), 1515-1524. https://doi.org/10.1139/cjfr-2014-0221

Johnston, S. R. Fungus-bacteria interactions in decomposing wood: unravelling community effects. Cardiff University. (2017).

Jomura, M., Kominami, Y., Dannoura, M., & Kanazawa, Y. Jomura, M., Kominami, Y., Dannoura, M., & Kanazawa, Y. Spatial variation in respiration from coarse woody debris in a temperate secondary broad-leaved forest in Japan. Forest Ecology and Management. (2008). 255(1), 149-155. https://doi.org/10.1016/j.foreco.2007.09.002

Jones, J. M., Heath, K. D., Ferrer, A., Brown, S. P., Canam, T., & Dalling, J. W. J. F. m. e. Wood decomposition in aquatic and terrestrial ecosystems in the tropics: contrasting biotic and abiotic processes. (2019). 95(1), fiy223. https://doi.org/10.1093/femsec/fiy223

Kavanagh, K. Fungi: biology and applications: John Wiley & Sons. (2017). https://doi.org/10.1002/9781119374312

Keith, H., Mackey, B.G., & Lindenmayer, D. B. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. (2009). 106(28), 11635-11640. https://doi.org/10.1073/pnas.0901970106

Khan, K., Tuyen, T. T., Chen, L., Duan, W., Hussain, A., Jamil, M. A. Wang, Y. J. F. Nutrient Dynamics Assessment of Coarse Wood Debris Subjected to Successional Decay Levels of Three Forests Types in Northeast, China. (2021). 12(4), 401. https://doi.org/10.3390/f12040401

Kooch, Y., Bayranvand, M. J. F. E., & Management. Composition of tree species can mediate spatial variability of C and N cycles in mixed beech forests. (2017). 401, 55-64. https://doi.org/10.1016/j.foreco.2017.07.001

Kooch, Y., Ehsani, S., & Akbarinia, M. J. E. e. Stoichiometry of microbial indicators shows clearly more soil responses to land cover changes than absolute microbial activities. (2019). 131, 99-106. https://doi.org/10.1016/j.ecoleng.2019.03.009

Kooch, Y., Samadzadeh, B., & Hosseini, S. M. J. C. The effects of broad-leaved tree species on litter quality and soil properties in a plain forest stand. (2017). 150, 223-229. https://doi.org/10.1016/j.catena.2016.11.023

Krankina, O. N., Harmon, M. E., & Griazkin, A. V. J. C. J. o. F. R. Nutrient stores and dynamics of woody detritus in a boreal forest: modeling potential implications at the stand level. (1999). 29(1), 20-32. https://doi.org/10.1139/x98-162

Laiho, R., & Prescott, C. E. J. C. j. o. f. r. Decay and nutrient dynamics of coarse woody debris in northern coniferous forests: a synthesis. (2004). 34(4), 763-777. https://doi.org/10.1139/x03-241

Lamb, E. G., Kennedy, N., Siciliano, S. D. J. P., & Soil. Effects of plant species richness and evenness on soil microbial community diversity and function. (2011). 338(1), 483-495. https://doi.org/10.1007/s11104-010-0560-6

Lodge, D., McDowell, W. H., McSwiney, C. J. T. i. e., & evolution. The importance of nutrient pulses in tropical forests. (1994). 9(10), 384-387. https://doi.org/10.1016/0169-5347(94)90060-4

Magill, A. H., & Aber, J. D. Variation in soil net mineralization rates with dissolved organic carbon additions. Soil biology and biochemistry. (2000). 32(5), 597-601. https://doi.org/10.1016/S0038-0717(99)00186-8

Mäkipää, R., Rajala, T., Schigel, D., Rinne, K. T., Pennanen, T., Abrego, N., & Ovaskainen, O. Interactions between soil-and dead wood-inhabiting fungal communities during the decay of Norway spruce logs. (2017). 11(9), 1964-1974. https://doi.org/10.1038/ismej.2017.57

Marañón-Jiménez, S., & Castro, J. Effect of decomposing post-fire coarse woody debris on soil fertility and nutrient availability in a Mediterranean ecosystem. Biogeochemistry. (2013). 112, 519-535. https://doi.org/10.1007/s10533-012-9744-x

Maron, P. A., Sarr, A., Kaisermann, A., Lévêque, J., Mathieu, O., Guigue, J., ... & Ranjard, L. High microbial diversity promotes soil ecosystem functioning. Applied and Environmental Microbiology. (2018). 84(9), e02738-17. https://doi.org/10.1128/AEM.02738-17

Means, J. E., MacMillan, P. C., & Cromack Jr, K. Biomass and nutrient content of Douglas-fir logs and other detrital pools in an old-growth forest, Oregon, USA. Canadian Journal of Forest Research. (1992). 22(10), 1536-1546. https://doi.org/10.1579/0044-7447-31.2.113

Means, J. E., MacMillan, P. C., & Cromack Jr, K. Biomass and nutrient content of Douglas-fir logs and other detrital pools in an old-growth forest, Oregon, USA. Canadian Journal of Forest Research. (1992). 22(10), 1536-1546. https://doi.org/10.1139/x92-204

Merganičová, K., Merganič, J., Svoboda, M., Bače, R., & Šebeň, V. Deadwood in forest ecosystems. Forest Ecosystems–More than Just Trees, InTech Book. (2012). 81-108. https://doi.org/10.5772/31003

Metzger, K. L., Smithwick, E. A., Tinker, D. B., Romme, W. H., Balser, T. C., & Turner, M. G. Influence of coarse wood and pine saplings on nitrogen mineralization and microbial communities in young post-fire Pinus contorta. Forest Ecology and Management. (2008).256(1-2), 59-67. https://doi.org/10.1016/j.foreco.2008.03.043

Minghe, L., Guoyi, Z., Deqiang, Z., & Lili, G. Decomposition and nutrient release from coarse woody debris of {\sl Castanopsis chinensis} in Dinghushan forest ecosystem. Journal of Tropical and Subtropical Botany. (2006). 14(2), 107-112.

Mori, T., Lu, X., Aoyagi, R., & Mo, J. Reconsidering the phosphorus limitation of soil microbial activity in tropical forests. Functional Ecology. (2018). 32(5), 1145-1154. https://doi.org/10.1111/1365-2435.13043

Neher, D. A. Soil community composition and ecosystem processes: comparing agricultural ecosystems with natural ecosystems. Agroforestry Systems. (1999). 45, 159-18. https://doi.org/10.1023/A:1006299100678

Osman, K. T., & Osman, K. T. Nutrient dynamics in forest soil. Forest soils: properties and management,. (2013). 97-121. https://doi.org/10.1007/978-3-319-02541-4_6

Palozzi, J. E., & Lindo, Z.Boreal peat properties link to plant functional traits of ecosystem engineers. Plant and Soil. (2017). 418, 277-291. https://doi.org/10.1007/s11104-017-3291-0

Qi, Y., Li, J., Deng, S., Wang, J., Zhang, Y., Pei, H., Liu, Z. Long-term irrigation reduces soil carbon sequestration by affecting soil microbial communities in agricultural ecosystems of Northern China. European Journal of Soil Science. (2022). 73(1), e13143. https://doi.org/10.1111/ejss.13143

Rahman, M. M., Tsukamoto, J., Tokumoto, Y., & Shuvo, M. A. R. The role of quantitative traits of leaf litter on decomposition and nutrient cycling of the forest ecosystems. Journal of forest and environmental science. (2013). 29(1), 38-48. https://doi.org/10.7747/JFS.2013.29.1.38

Rajala, T., Peltoniemi, M., Pennanen, T., & Mäkipää, R. Fungal community dynamics in relation to substrate quality of decaying Norway spruce (Picea abies [L.] Karst.) logs in boreal forests. FEMS Microbiology Ecology. (2012). 81(2), 494-505. https://doi.org/10.1111/j.1574-6941.2012.01376.x

Ray, M. J., Leak, D. J., Spanu, P. D., & Murphy, R. J. Brown rot fungal early stage decay mechanism as a biological pretreatment for softwood biomass in biofuel production. Biomass and bioenergy. (2010). 34(8), 1257-1262. https://doi.org/10.1016/j.biombioe.2010.03.015

Rinne-Garmston, K. T., Peltoniemi, K., Chen, J., Peltoniemi, M., Fritze, H., & Mäkipää, R. (2019). Carbon flux from decomposing wood and its dependency on temperature, wood N2 fixation rate, moisture and fungal composition in a Norway spruce forest. Global Change Biology, 25(5), 1852-1867. https://doi.org/10.1111/gcb.14594

Sierra, C. A. Spatial and temporal variability of carbon dynamics in a tropical forest of Colombia. (2006).

Sinsabaugh, R. L., Lauber, C. L., Weintraub, M. N., Ahmed, B., Allison, S. D., Crenshaw, C., & Zeglin, L. H. Stoichiometry of soil enzyme activity at global scale. Ecology letters. (2008). 11(11), 1252-1264. https://doi.org/10.1111/j.1461-0248.2008.01245.x

Spears, J. D., Holub, S. M., Harmon, M. E., & Lajtha, K. The influence of decomposing logs on soil biology and nutrient cycling in an old-growth mixed coniferous forest in Oregon, USA. Canadian Journal of Forest Research. (2003). 33(11), 2193-2201. https://doi.org/10.1139/x03-148

Sterilized, S., & Sterilized, P. M. Enhanced phosphatase activity in earthworm casts is more of microbial origin. Current Science. (2000). 79(9), 1158.

Stokland, J. N., Tomter, S. M., & Söderberg, U. Development of dead wood indicators for biodiversity monitoring: experiences from Scandinavia. Monitoring and indicators of forest biodiversity in Europe—from ideas to operationality. (2004). 51, 207-226.

Tarus, G. K., & Nadir, S. W. Effect of forest management types on soil carbon stocks in montane forests: a case study of eastern mau forest in Kenya. International Journal of Forestry Research. (2020). 1-10. 2020. https://doi.org/10.1155/2020/8862813

Ulyshen, M. D., Shefferson, R., Horn, S., Taylor, M. K., Bush, B., Brownie, C., ... & Strickland, M. S. Below-and above-ground effects of deadwood and termites in plantation forests. Ecosphere. (2017). 8(8), e01910. https://doi.org/10.1002/ecs2.1910

Van der Wal, A., Geydan, T. D., Kuyper, T. W., & De Boer, W. A thready affair: linking fungal diversity and community dynamics to terrestrial decomposition processes. FEMS Microbiology reviews. (2013). 37(4), 477-494. https://doi.org/10.1111/1574-6976.12001

Walker, T. W., Kaiser, C., Strasser, F., Herbold, C. W., Leblans, N. I., Woebken, D., & Richter, A. Microbial temperature sensitivity and biomass change explain soil carbon loss with warming. Nature climate change. (2018). 8(10), 885-889. https://doi.org/10.1038/s41558-018-0259-x

Wang, H., Wu, J., Li, G., & Yan, L. Changes in soil carbon fractions and enzyme activities under different vegetation types of the northern Loess Plateau. Ecology and evolution. (2020). 10(21), 12211-12223. https://doi.org/10.1002/ece3.6852

Wang, Q., Xiao, F., Wang, S., & Xu, G. Response of selected soil biological properties to stump presence and age in a managed subtropical forest ecosystem. Applied soil ecology. (2012). 57, 59-64.

https://doi.org/10.1016/j.apsoil.2012.02.019

Warner, D. L., Villarreal, S., McWilliams, K., Inamdar, S., & Vargas, R. Carbon dioxide and methane fluxes from tree stems, coarse woody debris, and soils in an upland temperate forest. Ecosystems. (2017). 20, 1205-1216. https://doi.org/10.1007/s10021-016-0106-8

Weedon, J. T., Cornwell, W. K., Cornelissen, J. H., Zanne, A. E., Wirth, C., & Coomes, D. A. Global meta-analysis of wood decomposition rates: a role for trait variation among tree species?. Ecology Letters. (2009). 12(1), 45-56. https://doi.org/10.1111/j.1461-0248.2008.01259.x

Wilcke, W., Hess, T., Bengel, C., Homeier, J., Valarezo, C., & Zech, W. Coarse woody debris in a montane forest in Ecuador: mass, C and nutrient stock, and turnover. Forest Ecology and Management,. (2005). 205(1-3), 139-147. https://doi.org/10.1016/j.foreco.2004.10.044

Woodall, C. W., & Liknes, G. C. Climatic regions as an indicator of forest coarse and fine woody debris carbon stocks in the United States. Carbon balance and management. (2008). 3, 1-8. https://doi.org/10.1186/1750-0680-3-5

Wu, C., Zhang, Z., Wang, H., Huang, G., Shu, C., Kong, F., & Liu, Y. Home-field advantage of CWD decomposition in subtropical forests varied by field sites. Forest ecology and management. (2019). 444, 127-137. https://doi.org/10.1016/j.foreco.2019.04.051

Yuan, J., Hou, L., Wei, X., Shang, Z., Cheng, F., & Zhang, S. Decay and nutrient dynamics of coarse woody debris in the Qinling Mountains, China. PLoS One. (2017). 12(4), e0175203. https://doi.org/10.1371/journal.pone.0175203

Yuan, J., Hou, L., & Zhang, S. X.Research progress in coarse woody debris. Journal of Northwest Forestry University. (2011). 26(4), 90-98.

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