

Precipitation and air temperature control the variations of dissolved organic matter along an altitudinal forest gradient, Gongga Mountains, China

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Abstract Dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) contribute significantly to C and N cycling in forest ecosystems. Little information is available on the variations in the DOC and DON concentrations and depositions in bulk and stand precipitation within forests along an altitudinal gradient. To determine the temporal variations in the DOC and DON concentrations and depositions in different forests and the spatial variations along the elevation gradient, the DOC and DON concentrations and depositions were measured in bulk precipitation, throughfall, and stemflow within three forest types, i.e., broadleaf forest (BLF), broadleaf-coniferous forest (BCF), and coniferous forest (CF), during the wet season (May to October) on Gongga Mountain, China, in 2015. The concentrations of bulk precipitation in BLF, BCF, and CF were 3.92, 4.04, and 2.65 mg L⁻¹, respectively, for DOC and were 0.38, 0.26, and 0.29 mg L⁻¹, respectively, for DON. BCF had the highest DOC deposition both in bulk precipitation (45.12 kg ha⁻¹) and stand precipitation (98.52 kg ha⁻¹), whereas the highest DON deposition was in BLF (3.62 kg ha⁻¹ bulk precipitation and 4.11 kg ha⁻¹ stand precipitation) during the study period. The meteorological conditions of precipitation and air temperature significantly influenced the dissolved organic matter (DOM) depositions along the elevation gradient. The leaf area index did not show

any correlation with DOM depositions during the growing season.

Keywords Dissolved organic carbon · Dissolved organic nitrogen · Forest · Precipitation · Air temperature · Leaf area index

Introduction

In forest ecosystems, water is the transporting media and solvent of nutrients, and therefore, nutrient cycles are closely related to hydrological cycles (Battin et al. 2009). Although inorganic matter is a major contributor to the nutrient pool in some forests (Izquieta-Rojano et al. 2016), dissolved organic matter (DOM) composed of dissolved organic carbon (DOC) and nitrogen (DON) plays a significant role in biogeochemical cycling in forest ecosystems (Kindler et al. 2011). The quantity and quality of atmospheric DOM depositions show obvious changes when they go through the canopy to the forest floor and provide potential direct N sources for plants (Neff et al. 2003) or an indirect source of CO₂ emission to the atmosphere (Cole et al. 2007).

The DOC and DON concentrations and the fluxes of bulk precipitation vary across different regions and land use types. The concentrations reported in the existing literature range from 0.3 to 4.7 mg L⁻¹ of DOC and 0 to 0.29 mg L⁻¹ of DON in bulk precipitation over forest catchments (Van Stan 2012). Pan et al. (2010) studied 10 various sites in northern China and found that the DOC concentrations and deposition fluxes ranged from 2.4 to 3.9 mg L⁻¹ and from 14 to 27 kg ha⁻¹ year⁻¹, respectively. The DOC and DON found in precipitation are likely from biogenic sources, e.g., biogenic emission from vegetation (Siudek et al. 2015), forest fires or

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dust (Willey et al. 2000), and anthropogenic activities (Avery et al. 2013).

The chemical composition and deposition fluxes of stand precipitation, including throughfall and stemflow, tend to be related to atmospheric deposition. In most cases, because of the flushing of dry deposition on the leaves or stems, the DOC concentrations of stand precipitation are often an order of magnitude higher than those of precipitation. Conversely, forest canopies are likely to retain N in areas with low N deposition (Duchesne and Houle 2006). Moreover, different stand types with varied inter-canopy structure and morphology (e.g., bark types, leaf shapes, and crown form) lead to differences in stand precipitation chemistry and deposition (Bischoff et al. 2015; Izquieta-Rojano et al. 2016). Previous researchers found higher DOC and DON concentrations in stand precipitation within coniferous forests compared to those in deciduous forests due to the more intensive leaching of DOC and DON from a dense canopy (Inamdar and Mitchell 2007). Additionally, DOM concentrations and fluxes are linked to meteorological conditions such as precipitation amount and temperature. For example, Schmidt et al. (2010) found that the DOM fluxes were positively related to the bulk precipitation fluxes, and Wu et al. (2009) observed positive correlation between DOM concentrations in throughfall and air temperature.

The relationship between the nutrient cycle and the hydrological cycle has been studied in many previous investigations, especially wet and dry deposition. However, there are still many gaps. First, most of the studies focus on either the DOC or DON concentrations or fluxes (Izquieta-Rojano et al. 2016; Siudek et al. 2015). Although DOC and DON have different patterns of change in the hydrological cycle of forest ecosystems (Michalzik et al. 2001), the stoichiometry of carbon and nitrogen in the forest biochemical cycle has been reported in many studies. For example, the ratios of C/N tend to be a possible indicator for the N saturation of forest ecosystems (Wu et al. 2009). Furthermore, most of the previous research focused on the large-volume contributors (bulk precipitation and throughfall) and ignored the stemflow in the study of the nutrient cycle, which can lead to an underestimation of the nutrient pools or fluxes. Generally, although the amount of stemflow is much lower than throughfall, stemflow is highly chemically enriched water and a considerable and preferential transport to the subsurface water flux (Germer et al. 2010; Van Stan and Levia 2010). In addition, different forest types showed various dynamics of the DOC or DON concentrations and fluxes, and controversy still exists regarding the effect that vegetation canopy has on both the quantity and quality of DOC and DON (Michalzik et al. 2001). Nevertheless, few studies have focused on a comparison of the DOC or DON concentrations and fluxes in different forest types or on the identification of dominant factors controlling the variation of DOM depositions, particularly along the mountain altitude with several vegetation zones.

Gongga Mountain is located at the eastern border of the Tibetan Plateau. The eastern slope of Mt. Gongga is characterized by a high mountain and a deep valley with a complete vertical vegetation zone, which is an ideal area to investigate the variations in DOM concentrations and fluxes and the dynamic patterns in different forest types. This study measured the DOC and DON concentrations and depositions of bulk precipitation, throughfall, and stemflow during the wet season in eight plots along a 1700-m altitudinal forest gradient that included three forest types: broadleaf forest (BLF), broadleaf and coniferous forest (BCF), and coniferous forest (CF). Consequently, the purposes of this work are (1) to quantify the DOC and DON concentrations and depositions of bulk precipitation and stand precipitation in three different forest types and (2) to identify the main factors influencing the variations in DOM depositions along the altitudinal forest gradient.

Methods

Site description

The study plots were located in the eastern slope of Gongga Mountain (29° 20′–30° 20′ N, 101° 30′–102° 15′ E). Mt. Gongga is located on the transitional zone of the eastern monsoon subtropics and the frigid area of the Tibetan Plateau in China. The eastern slope of Mt. Gongga has a relative height difference of 6400 m within a 29-km horizontal distance, which results in the distribution of seven altitudinal vegetation zones along the slope. The forest zone includes broad-leaved evergreen forests, broad-leaved deciduous forest, mixed coniferous and broad-leaved forest, and coniferous forest. Because of the amenable habitat, most of the forests have multiple canopy layers. There are two long-term monitoring meteorological stations at 1600 and 3000 m a.s.l. The mean annual temperature (MAT) and mean annual precipitation (MAP) are 12.7 °C and 1050.3 mm at 1600 m a.s.l. (from 1992 to 2010) and 4.2 °C and 1947.4 mm at 3000 m a.s.l. (from 1988 to 2010), respectively. The wet season is from May to October, in which the precipitation accounts for 86.9% at 1600 m and 79.7% at 3000 m of the yearly total (Wu et al. 2013).

The study plots selected in this study are at 2000–3700 m a.s.l. and include BLF, BCF, CF; details of the plots are shown in Table 1.

Sampling and chemical analysis

There are six meteorological stations from 1600 m a.s.l. to the forest line (3665 m a.s.l.). The bulk precipitation amounts were recorded in these stations. In those sampling plots without recorded data, the bulk precipitation amounts were interpolated according to the linear relationship between the

Table 1 Meteorology, geographic features, and vegetation of sampling sites

Plot	Elevation (m a.s.l.)	AT ^a (°C)	PR ^a (mm)	Dominant vegetation	LAI ^b
Broadleaf forest (BLF)					
P1	2017	9.35	1104.5	<i>Toxicodendron vernicifluum</i> (Stokes) F.A. Barkley, <i>Salix babylonica</i> L., <i>Fraxinus chinensis</i>	3.40 ± 0.93
P2	2291	8.09	1280.8	<i>Lithocarpus cleistocarpus</i> , <i>Acer</i> L., <i>Cercidiphyllum japonicum</i> Sieb. Et Zucc., <i>Cinnamomum camphora</i> (L.) Presl.	4.39 ± 0.74
P3	2455	7.33	1360.6	<i>Acer</i> L., <i>Betula albo-sinensis</i> Burk., <i>Cercidiphyllum japonicum</i> Sieb. Et Zucc.	4.49 ± 1.01
Broadleaf-coniferous forest (BCF)					
P4	2759	5.93	1508.6	<i>Picea brachytyla</i> (Franch.) Pritz., <i>Abies fabri</i> (Mast.) Craib, <i>Betula albo-sinensis</i> Burk., <i>Acer</i> L.	3.45 ± 0.75
P5	3000	4.91	1625.8	<i>Abies fabri</i> (Mast.) Craib, <i>Picea brachytyla</i> (Franch.) Pritz., <i>Populus purdomii</i> Rehd., <i>Betula albo-sinensis</i> Burk	4.31 ± 1.41
Coniferous forest (CF)					
P6	3326	3.57	1178.8	<i>Abies fabri</i> (Mast.) Craib, <i>Rhododendron simsii</i> Planch., <i>Sorbus pohuashanensis</i>	4.22 ± 1.20
P7	3567	2.56	1405.7	<i>Abies fabri</i> (Mast.) Craib, <i>Rhododendron simsii</i> Planch.	3.20 ± 0.57
P8	3665	2.15	1367.6	<i>Abies fabri</i> (Mast.) Craib, <i>Rhododendron simsii</i> Planch.	3.63 ± 0.58

AT mean annual temperature, PR annual precipitation

^a Data in P2, P4, P5, P6, and P7 were from the nearest meteorological stations. Data in P1, P3, and P8 were interpolated using a linear equation according to the elevation gradient

^b LAI data are shown as the mean ± SD

rainfall amount and elevation. Five bulk precipitation collectors (20 cm in diameter) were installed in each plot at a height of 0.5 m above the ground in an open field. To avoid contamination by litter fall or insects, a nylon mesh was placed in the collectors. Throughfall was sampled with 25 collectors (the same type as the bulk precipitation collectors) that were distributed systematically in each plot and partially buried to keep the samples cool. The volume in each collector was determined, and all of the samples were then mixed into one subsample for each plot. Five trees were selected according to the species and size class structure. A tube (2.5 cm in diameter) was attached to the selected trees around the circumference of the trunk from diameter at breast height (DBH) and connected to a 5-L sampler. The gaps between the tube and trunk were sealed with silicone sealant. All of the volumes were measured, and subsamples were taken from all of the samplers at each sampling event. The subsamples in each plot were bulked together with subsample volumes weighted to tree diameters. All of the collectors were cleaned after sampling using deionized water.

All of the samples were taken from May to the end of October 2015. The volumes of throughfall and stemflow were measured manually three times a month with a measuring cylinder from June to September and twice a month in May and October because the precipitation amount was low. After volumes measuring, samples in precipitation, throughfall, and stemflow collectors were mixed separately into three subsamples. In total, 48 subsamples were taken in each plot over the study period.

The samples were kept in coolers during transport and then filtered with a filter membrane (0.45 μm) in laboratory. The samples were stored at 4 °C in the dark and were analyzed

within 48 h of collection. The concentrations of DOC and total dissolved nitrogen (TDN) were analyzed using a liquid carbon and nitrogen analyzer (Elementar, Vario TOC, Germany). The concentrations of ammonium (N-NH₄⁺) and nitrate (N-NO₃⁻) were determined using a continuous flow analyzer (Seal, AA3, Germany).

The leaf area index (LAI) was measured using a canopy analyzer (LI-COR, LAI-2200, USA) every month in each plot from May to October.

Data analysis

The amounts of throughfall were converted to rainfall depth for comparison with the bulk precipitation using the following equation:

$$T_f = \frac{4V}{10\pi D^2}$$

where T_f is the throughfall depth (mm), V is the water volume in each throughfall collector (mL), and D is the diameter of collector (cm).

The stemflow of individual trees were scaled to the entire plot according to the following equation (McJannet et al. 2007):

$$V_p = \frac{V_s \times B_p}{B_s}$$

$$S_f = \frac{V_p}{10^3 A}$$

where V_p is the volume of entire plot (mL), B_p is the basal area of plot (cm^2), B_s is the basal area of the sample tree (cm^2), S_f is the stemflow depth (mm), and A is the plot area (m^2).

The DON concentrations of the water samples were calculated according to the following equation:

$$C_{\text{TON}} = C_{\text{TDN}} - (C_{\text{N-NH}_4^+} + C_{\text{N-NO}_3^-})$$

where C_{TON} is the TON concentration (mg L^{-1}), C_{TDN} is the TDN concentration (mg L^{-1}), $C_{\text{N-NH}_4^+}$ is the concentration of N-NH_4^+ (mg L^{-1}), and $C_{\text{N-NO}_3^-}$ is the N-NO_3^- concentration (mg L^{-1}).

The deposition of DOM was calculated by multiplying the water volume by the corresponding DOM concentration of the sample. The monthly fluxes of DOM in each plot were calculated as the sum of each sampling DOM deposition over the whole month. The monthly mean concentrations of DOM were the monthly fluxes divided by the total water amount in 1 month. The stand deposition was the sum of throughfall and stemflow depositions. The monthly DOM bulk depositions and stand depositions were used to identify the relationship to monthly precipitation amount, air temperature, and LAI.

To identify the effects of canopy types on the DOM deposition transported to the forest floor, the enrichment ratio was determined with the following equation:

$$R = \frac{D_b - D_s}{D_b} \times 100\%$$

where R is the enrichment ratio of DOM deposition, D_b is the deposition of bulk precipitation, and D_s is the deposition of stand precipitation.

Repeated analysis of variation (ANOVA) was used to compare the DOM concentrations and depositions between bulk precipitation and stand precipitation under the three forest types. Repeated ANOVA was also used to identify the differences in the enrichment ratio among the three forest types. To identify the dominant factors in variations of DOM depositions along the elevation gradient, multiple regression analysis was applied. Principal component analysis (PCA) was used to quantify the contributions of meteorological factors (mainly the precipitation and air temperature) and LAI to the DOM deposition in the three forests. All of the statistical analyses were conducted using SPSS 20 software.

Results

Monthly variations of DOC and DON concentrations

The temporal variations of DOC and DON concentrations are shown in Fig. 1. There was no detectable difference in the DOC concentration between the bulk precipitation in BLF

and that in BCF ($p = 0.781$). However, the DOC concentrations of throughfall in BCF were consistently higher than those in BLF. The DOC concentrations of stemflow in BCF were the highest and were lowest in BLF during the study period. Regarding DON concentrations, there were no detectable differences in bulk precipitation and in stemflow among the three stand types ($p > 0.05$ for each). The DON concentrations of throughfall in BLF were higher than those of the other two forest types.

Significant variations were found between the DOM concentrations of bulk precipitation and stand precipitation. Compared with the DOC concentrations of bulk precipitation, the DOC concentrations of both throughfall and stemflow were extremely high in each stand type. Similar results were shown for the DON concentrations between bulk precipitation and stand precipitation, although no detectable differences were found between bulk precipitation and throughfall in CF ($p = 0.333$).

Throughout the study period, the mean DOC concentrations were highest both in bulk precipitation and stand precipitation in BCF (Table 2). Although the mean DOC concentration of bulk precipitation in BLF was higher than that in CF, the mean stand concentrations were lower in BLF than in CF. The highest mean DON concentrations of bulk precipitation and throughfall were in BLF, and the highest mean DON concentration of stemflow was in BCF.

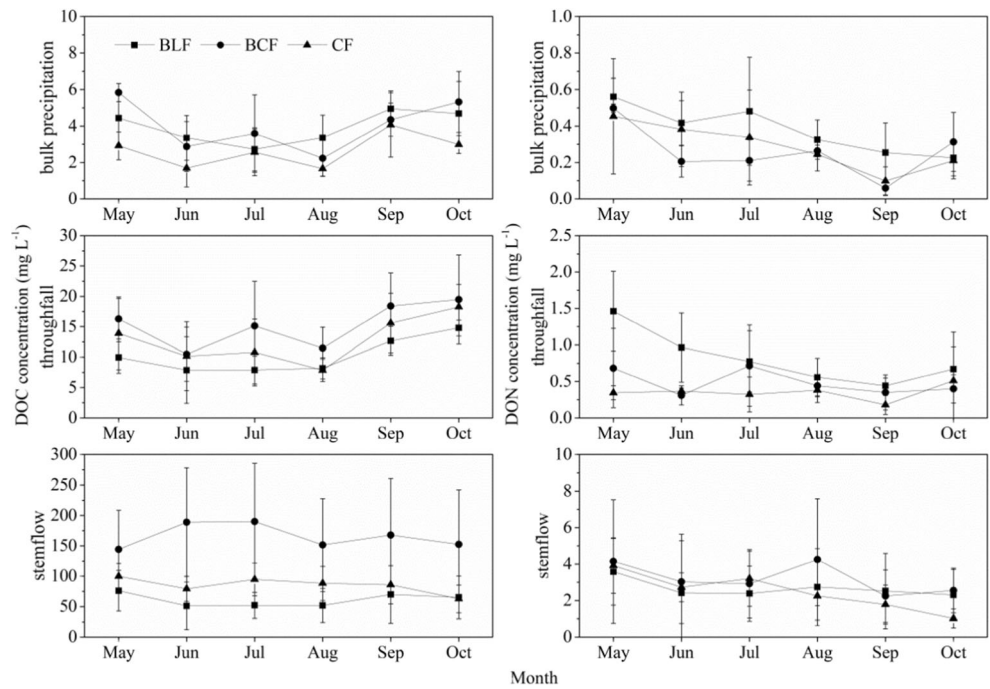
Monthly variations of DOC and DON depositions

DOC depositions in bulk precipitation in CF were the lowest, but the lowest DOC depositions in stand precipitation during the study period were in BLF. However, there were no detectable differences in DOC depositions between the bulk precipitation of BLF and BCF ($p = 0.179$) or the stand precipitation of BCF and CF ($p = 0.111$). For the DON bulk depositions, no statistically significant differences were found between BLF and BCF ($p = 0.168$) or between BCF and CF ($p = 0.895$). The same patterns were found in stand depositions.

The monthly variations in the DOC and DON depositions in various stand types are shown in Fig. 2. The DOC depositions in stand precipitation were significantly higher than those in bulk precipitation in each stand. Conversely, there were no detectable differences in DON depositions between bulk precipitation and stand precipitation ($p > 0.05$ for each). The DOC enrichment ratios were varied in different forest types, but different DON enrichment ratios were not found among the three stand types ($p > 0.05$ for each).

During the sampling period, the DOC depositions of stand precipitation were consistently higher than those of bulk precipitation (Table 2). The enrichment ratios of DOC depositions were $\text{CF} > \text{BCF} > \text{BLF}$. Conversely, the enrichment ratios of DON depositions were $\text{CF} < \text{BCF} < \text{BLF}$.

Fig. 1 Monthly variations in DOC and DON concentrations in bulk precipitation, throughfall, and stemflow



Impact factors on variations of DOC and DON depositions

The DOM depositions did not show any regular trend along the elevation gradient ($p > 0.05$), except for stand DON depositions (Fig. 3). The DOC depositions both in bulk precipitation and stand precipitation increased from the lowest elevation to reach the highest value in P4 (2759 m a.s.l.) and then showed a declining trend at higher elevation. However, there

was a slightly decreasing tendency in DON depositions from P1 (2017 m a.s.l.) to the tree line (3665 m a.s.l.).

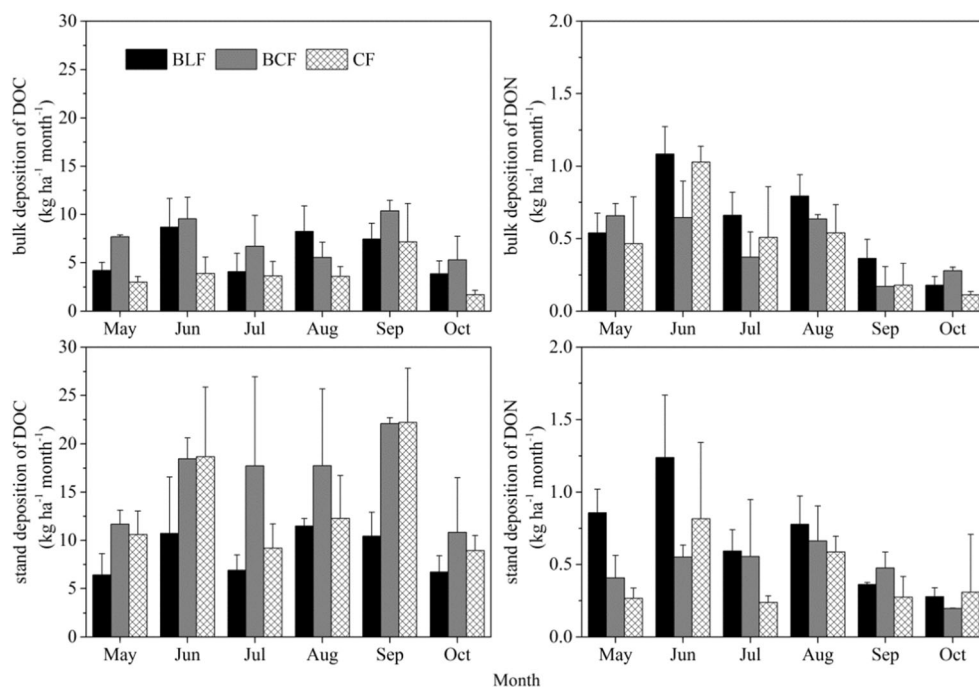
According to the multiple regression analysis (Table 3), LAI did not show any correlation with DOM depositions either in bulk precipitation or stand precipitation ($p > 0.05$). However, the meteorological factors of both precipitation amount and air temperature were significantly correlated with the DOM depositions. Specifically, the relationships between

Table 2 DOC and DON mean concentrations and depositions (May to October 2015) in bulk precipitation and stand precipitation in three forest types

	Concentration (mg L ⁻¹)		Deposition (kg ha ⁻¹)		Enrichment rate (%)		DOC/DON ratio
	DOC	DON	DOC	DON	DOC	DON	
Broadleaf forest					44.06	13.54	
Bulk precipitation	3.92 ± 1.04	0.38 ± 0.03	36.56 ± 8.64	3.62 ± 0.35			10.01
Throughfall	10.23 ± 0.70	0.81 ± 0.14	51.54 ± 8.01	4.06 ± 0.43			
Stemflow	61.09 ± 33.00	2.66 ± 1.34	1.13 ± 0.13	0.05 ± 0.01			
Total below canopy			52.67 ± 8.05	4.11 ± 0.43			12.82
Broadleaf and coniferous forest					118.35	3.62	
Bulk precipitation	4.04 ± 0.90	0.26 ± 0.01	45.12 ± 8.51	2.76 ± 0.09			16.35
Throughfall	15.21 ± 4.79	0.48 ± 0.21	95.89 ± 29.35	2.82 ± 1.01			
Stemflow	165.75 ± 95.44	3.19 ± 2.58	2.63 ± 2.28	0.04 ± 0.03			
Total below canopy			98.52 ± 27.07	2.86 ± 0.98			34.45
Coniferous forest					255.47	-12.01	
Bulk precipitation	2.65 ± 0.40	0.29 ± 0.14	23.04 ± 5.29	2.83 ± 1.12			8.14
Throughfall	12.77 ± 0.57	0.35 ± 0.07	80.52 ± 15.21	2.45 ± 0.6			
Stemflow	85.11 ± 16.54	2.48 ± 0.35	1.38 ± 0.35	0.04 ± 0.02			
Total below canopy			81.90 ± 14.87	2.49 ± 1.01			32.89

DOM concentrations and deposition data are shown as the mean ± SD

Fig. 2 Monthly variations in DOC and DON depositions in bulk precipitation and stand precipitation



precipitation amount and DOC depositions ($p < 0.01$) were more significant than those between air temperature and DOC depositions both in bulk precipitation and stand precipitation, whereas a more significant correlation was shown for DON deposition and air temperature with stand precipitation ($p < 0.01$). The combination of precipitation and air temperature could explain 93.58, 90.57, and 94.05% of the DOM deposition in BLF, BCF, and CF, respectively, based on the principal component analysis, which meant that the LAI only contributed a small portion to the DOM deposition in the three forests.

Discussion

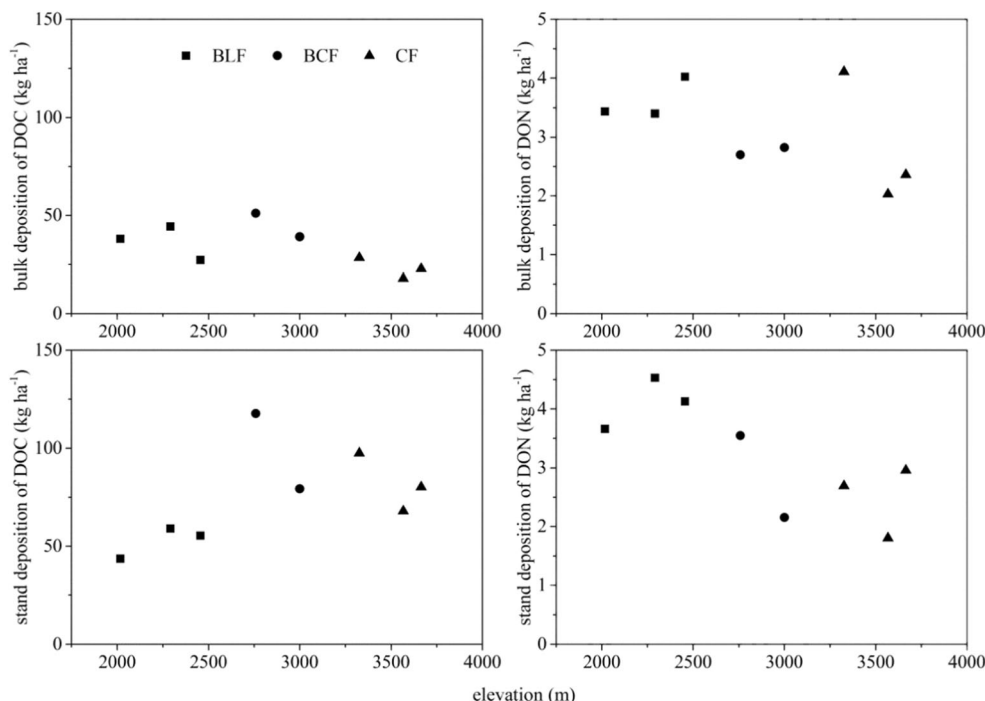
Variations in DOC and DON concentrations and depositions

The average DOC concentrations of bulk precipitation in the study area were 3.92, 4.04, and 2.65 mg L⁻¹ in BLF, BCF, and CF, respectively, which were within the range of the values reported in other studies. However, these values were higher than those in Flanders, where the mean DOC concentrations were about 2.1 and 2.3 mg L⁻¹ in deciduous forests and coniferous forests, respectively (Verstraeten et al. 2014). The mean DOC concentrations in deciduous forests and coniferous forests of Canada were higher than those in our research area (Pelster et al. 2009). The high DOM concentrations in bulk precipitation were due to increasing water fluxes with large sources of potential DOM (Izquieta-Rojano et al. 2016). One of main sources of DOM is from anthropogenic

activities. According to previous studies, combustion processes can contribute approximately 20–30% of the DOC found in atmospheric water (Avery et al. 2006). Siudek et al. (2015) compared the DOC concentrations in urban and forest sites in central Poland and found the causes of the seasonal patterns of DOC. The combination of natural and anthropogenic activities influenced the DOC concentrations in atmosphere during the warm season, whereas the anthropogenic activities (e.g., wood burning, coal combustion) controlled the increased DOC concentration during the cold season.

The average DOC concentrations in throughfall were at the high end of the range for the corresponding forest types. The DOM in throughfall was the combination of washing off or interception deposition on the canopy surface, leaf uptake, or assimilation by epiphytes and microorganisms. The dry organic matter on the canopy surface would be one of the major sources of throughfall deposition. Although the east slope of Mt. Gongga is rich in green vegetation, there are intensive anthropological activities such as vehicle emissions and construction work in this area. As a result, the DOM concentrations and deposition rates were closely correlated to the intensification of anthropological pollution. Studies have reported that the throughfall in coniferous forest contains higher DOC concentrations than that in deciduous forest, suggesting that the stand types also affect the DOM concentrations and deposition rates. Different structures (e.g., LAI, density of the canopy, and the inclination of the branches) result in different interception abilities. A longer interception time tends to enhance the DOM concentration by flushing. Conversely, dense canopy also increases the interception amount, leading to a decrease in the throughfall amount. Therefore, it was difficult

Fig. 3 DOC and DON depositions in bulk precipitation and stand precipitation along the elevation gradient



to determine the positive or negative effects of different forests on DOM depositions in stand precipitation by comparing the DOM deposition rates in various forest types.

The mean DOM concentrations in stemflow were higher than those of bulk precipitation and throughfall among the three stands. Generally, bark surface morphologies have a significant influence on the DOM concentrations in stemflow (Van Stan et al. 2011). The larger surface area in rough bark species means longer hydrological retention times for washing off the dry matter attached to the stem and exchanging ions (Germer et al. 2007). The DOM deposition rates in stemflow are related not only to the DOM concentrations but also to the stemflow amount. The stemflows were usually calculated as a depth equivalent per unit of projected area, but this method did not consider how the stemflow is input into the soil. Stemflow only infiltrates at the soil surface around the stem base and is not evenly redistributed below the canopy. Thus, if it was considered as the depth equivalent per unit basal area, the stemflow amount would be considerably enhanced (Van Stan 2012).

The winter depositions were not measured in this study because of the difficulty in accessing some sampling plots. This will definitely underestimate the annual flux, although the rainfall amount in the wet season was approximately 80% of annual rainfall. Previous studies have noted the seasonal pattern of DOC and DON concentrations and fluxes in stand precipitation (Izquieta-Rojano et al. 2016; Pelster et al. 2009). In most cases, the DOC fluxes were greater during the active growing season than in the dormant season. The increased canopy area extends the retention time for chemical washoff and exchange during the active season. The warmer climate also provides more suitable conditions for microbial activity. Draaijers et al. (1997) also found an increased DOC concentration in coniferous forest, suggesting that additional sources of DOC such as weak organic acids, rather than dry deposition, occurred in the forest canopy. The seasonal changes of DOC were stronger than those of DON (Inamdar and Mitchell 2007; Michalzik et al. 2001), and there was no consistent conclusion on the seasonal pattern of DON concentration and flux. Pelster et al. (2009) did not find significant

Table 3 Significance of multiple regression analysis between DOM depositions and precipitation (P), air temperature (T), and LAI along the elevation gradient

	DOC		DON	
	Bulk deposition	Stand deposition	Bulk deposition	Stand deposition
P	0.006**	0.000**	0.001**	0.015*
T	0.019*	0.031*	0.008**	0.002**
LAI	0.233	0.470	0.144	0.107

* $p < 0.05$, ** $p < 0.01$

differences in the DON concentrations in various seasons, whereas Morris et al. (2003) reported that the DON concentrations in winter were close to zero.

Influence of overstory vegetation on DOM depositions

The vegetation cover influences the quantity of DOM depositions from the atmosphere to the forest floor. Most previous studies illustrated that the DOC depositions in stand precipitation were several times higher than those in bulk precipitation (Pelster et al. 2009; Schmidt et al. 2010; Verstraeten et al. 2014). We observed similar results in different forest types, and coniferous forest showed the strongest enrichment effect to DOC deposition. During the warm season, the broadleaf forest had a higher LAI and interception capacity because of a larger biodiversity and more multiple canopies. Compared with broadleaf forest, coniferous forest intercepted less rainfall. Thus, the stand precipitation amount was higher than that of other stand types and leached more DOC to forest floor through flushing organic matter from leaves and stems because the DOC deposition rates were positively correlated with precipitation amount. The strong enriched capacity of DOC in the three stands implies that the study area forest catchment was C-rich. In contrast, weaker enrichment effects of DON were shown in the present study. Many studies have reported the retention of N in the canopy through absorption onto the foliage/stem surface, leaf uptake, or assimilation by epiphytes and microorganisms (Krupa 2003; Lovett 1994; Wilson 1992). Pelster et al. (2009) implied that the forest canopy tended to uptake inorganic nitrogen due to the inconsistent effect of vegetation cover on the different N compositions. However, abundant epiphytes exist in coniferous forest, so a portion of DON would possibly be assimilated, which suggests that coniferous forest is N-limited to epiphytes in this area.

Conversely, vegetation canopies also affect the quality of DOM depositions in stand precipitation. The changes observed in the C/N ratios from bulk precipitation to stand precipitation were similar to those found in a study conducted in Canada (Pelster et al. 2009). The C/N ratios would not change during the process of washing dry organic matter off the stems and foliage; the increasing C/N suggested that C and N sources were being assimilated or increasing in canopies or that different sources of organic matter other than atmospheric deposition were added to the stand precipitation. This is consistent with our finding that the enrichment effects of DOC are stronger than DON. Moreover, Draaijers et al. (1997) found that organic acids were leached from foliage. Plant species with smoother bark tend to have lower aromaticity because of the shorter hydrologic residence time that weakens the dissolution of aromatic organic compounds from bark surfaces (Guggenberger et al. 1994). In stands where the washoff compounds contain significant portions of biodegradable hydrophilic neutral carbohydrates, the

DOC content will change rapidly as microbial metabolism occurs (Helms et al. 2008; Michalzik et al. 2001). In addition, the contribution of DOM to total dissolved matter increases, according to previous researchers. Pelster et al. (2009) found that inorganic nitrogen was the major contributor to the nitrogen sources in bulk deposition but that the DON accounted for just 28% of N in bulk deposition; however, the percentage of organic nitrogen in total nitrogen varied from 41 to 54% in throughfall in various forests.

Main factors of the variations in DOM depositions along the elevation gradient

The meteorological conditions, such as precipitation amount and air temperature, have a more significant influence on DOM depositions than the LAI along the altitudinal forest gradient. The LAI, which is the ratio of projected leaf area to the floor area per unit, could be used as an index to forest structures. Although the forest zone in our study included three forest types, the LAI did not show any detectable differences in various forest types along the elevation gradient on Mt. Gongga ($p > 0.05$). In previous studies, coniferous forests had larger LAI than broadleaf forests. In contrast, the mean LAI in coniferous forests (3.68) was lower than that in broadleaf forests (4.09) in our study area. Multiple canopy layers are common on Mt. Gongga in both coniferous and broadleaf forests. However, coniferous forests consist of simple tree species (*Abies fabri* (Mast.) Craib and *Rhododendron simsii* Planch.), and the upper layer canopy is low density. Moreover, our study focused on the growing season when the broadleaved species were in their highest LAI period, so a larger LAI occurred in the broadleaf forests. Generally, a larger LAI means a higher canopy density. Denser canopy can intercept more precipitation and will decrease the stand precipitation, although the retention time will increase in denser canopy and result in higher DOM concentrations. Because of the complex effects of dense canopy, LAI showed little influence on the variation of DOM deposition in our study area. But we could not deny the contribution of forest structure to the DOM depositions.

Meteorological factors showed strongly increasing or decreasing trends along the elevation gradient on Mt. Gongga. The intensity of DOM depositions is related to the water volume and DOM concentrations. The stand precipitation volume is significantly correlated to the bulk precipitation, so higher precipitation amounts indicate greater bulk precipitation and stand precipitation. Many studies have found that large bulk precipitation volumes result in high DOM depositions (Schmidt et al. 2010). However, large precipitation volumes also enhance the dilution effect of the DOM concentrations, leading to low DOM depositions. The positive relationship between the precipitation volume and DOM depositions means that the effect of water fluxes on DOM depositions is

stronger than the dilution effect. In that case, a larger precipitation volume will result in higher DOM depositions in our study area. Air temperature also has an influence on the DOM depositions, especially on the DON depositions in bulk and stand precipitation. Organic nitrogen will transform to ammonia, nitrate, or nitrite through ammoniation and nitrification by bacteria. The changing meteorological conditions (temperature and humidity) will alter the ammoniation and nitrification abilities of the bacteria. Thus, DON depositions are strongly correlated to the temperature and bulk precipitation.

Conclusions

DOC and DON concentration and deposition showed different variations in broadleaf forest, broadleaf-coniferous forest, and coniferous forest. Overstory vegetation influenced DOC and DON concentration and deposition from the atmosphere to the forest floor which was related to the throughfall and stemflow. Different dynamic patterns in DOC and DON concentration and deposition were found during the study period. Specifically, all the three forests showed positive enrichment rates of DOC, while the enrichment rate of DON was negative in coniferous forest, suggesting that the study area was C-rich. Regarding the impact factors to the atmosphere and stand deposition, it is complicated to trace the completed processes of DOM, taking into consideration of the source, the route of transmission, and the interaction with plants. However, in a certain small catchment having large water amount, the transportation of DOM was mainly by physical processes (washing out, interception, retention, etc.). Consequently, the dominant factors controlling the variations of DOM deposition were the meteorological conditions rather than forest structure in our research.

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