Great fraction of dissolved organic C and N in the primary per-humid Chamaecyparis forest soil

Chih-Wei Tsai¹, Guanglong Tian² and Chih-Yu Chiu¹*

Abstract

Background: Labile organic matter plays a crucial role in a variety of forest functions, however, our understanding to its quality and quantity across various forests is limited, particularly primary forests. We investigated soil labile C and N (i.e. microbial biomass C and N, dissolved organic carbon (DOC) and nitrogen (DON), associated ammonium, and nitrate) at three topographic locations (i.e. summit, footslope and lakeshore) in a primary Chamaecyparis forest of Taiwan. The following hypotheses are tested in this study: (1) This undisturbed Chamaecyparis forest shows the great size of soil labile C and N; (2) there is an evident topographic effect on the distribution of soil labile C and N and the associated inorganic N over seasons.

Results: Fulfilling with our first hypothesis, the considerable size of labile C and N in this forest soil was quantified. Abundant C availability and the acidity of soils in this forest favoured ammonium production over nitrate. The undisturbed environment with per-humid and acidic soil was linked to the high concentrations of soil DOC and DON as the dominant form in N dynamics. In contrast to our second hypothesis, topographic effects on soil labile C and N were generally not evident, suggesting the homogeneous soil environment across various topographic locations in this Chamaecyparis forest.

Conclusions: This study illustrates the sustainable importance of primary montane forests for being sources of DOC and DON.

Keywords: Labile resource, DOC, DON, Ammonium, Nitrate

Background

Carbon and nitrogen play essential roles in developing, maintaining and reproducing of organisms. Transformation, movement and reuse of these nutrients are important to sustain a variety of ecosystem functions (Galloway et al. 2004). However, our understanding to the quality and quantity of soil labile C and N resources across various forests is still limited, in particular, subtropical primary montane forests. The ecological importance of soil organic matter lies in its biodegradability and availability for microbes, fauna and plant (Ghani et al. 2007). Thus, the comprehension of the size of soil labile C and N resources can help us understand the fraction of C and N immediately available to soil organisms and cycling in amount of C and N resources in forest ecosystems. Of these, microbial biomass C (Cmic) and N (Nmic) are the most labile C and N pools in soils. Although they generally constitute only 1–3 % and 1–5 % of total soil C and N (Moore et al. 2000), they are related to the size of decomposed organic material and soil physical and chemical properties.

Neff and Asner (2001) noted dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) constitute the main fraction of available monomers for microorganisms. The quantity of DOC can impact the heterotrophic microbial activity and the associated N transformation (Singh and Kashyap 2006). The proportion of DON and inorganic N can be an important indicator of water quality and nutrients in hydrological cycling (Fang et al. 

*Correspondence: bochiu@sinica.edu.tw
¹ Biodiversity Research Center, Academia Sinica, Taipei 11529, Taiwan
Full list of author information is available at the end of the article

© 2015 Tsai et al. This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.
With the shift of nitrogen cycling in forest ecosystems from organic to inorganic form, recent studies have shown that N can be lost from temperate forest ecosystems predominantly by the way of DON (Hedin et al. 1995; Perakis and Hedin 2002). So far, studies addressing the dynamics of labile C and N have mainly focused on temperate forests, but the potential contribution of subtropical primary forest soils to C and N loadings is still poorly known.

Chamaecyparis forests are valuable natural resources in eastern Asia because of its high quality timber, control of soil erosion, and storage of C and N. Much effort has been invested in investigating soil properties and fertility management of Japanese hinoki cypress (Chamaecyparis obtusa) plantations (e.g. Inagaki et al. 2008, 2011). By contrast, characteristics of soil organic matter under natural Chamaecyparis forests in subtropical montane area are not well known. Today, the Chamaecyparis forest in the Chi-Lan Mountain is one of the few preserved primary Chamaecyparis forests in northcentral Taiwan. The unique aspect of the Chamaecyparis forest is that it has the environment, which is rarely disturbed, high precipitation, and mild temperature.

Previous studies have shown that strongly acidic and wet environment resulted in the low diversity of soil bacterial communities in this region (Lin et al. 2010). The litter decomposition and humification in the Chamaecyparis forest is generally very slow (Chen et al. 2013; Chung et al. 2012), and this may result in the considerable soil organic matter and the great size of labile C and N loadings. Chen and Chiu (2000) investigated soil structure across a slope in the Chamaecyparis forest and found out a common phenomenon—a thick layer of organic horizon (i.e. 10–30 cm) derived from Sphagnum on the surface of soils. However, little is known about the size of the soil labile C and N in this primary Chamaecyparis forest. Additionally, Schmidt et al. (2010) demonstrated that DOC and DON were the predominant forms of C and N resources released from surface soils in a secondary Chamaecyparis forest of Taiwan. The objectives of the study were therefore to quantify concentrations of soil labile C and N under the Chamaecyparis forest and evaluate their distributions along topographic locations over seasons.

**Methods**

**Study area**

Surrounding a small and shallow lake, the primary Chamaecyparis forest is located in the Yuan Yang Lake Conserve area (24°35’N, 121°24’E). The Lake is small \((3.6 \times 10^4 \text{ m}^2)\) and shallow \((4.5 \text{ maximum depth})\). The annual precipitation is over 4000 mm and the annual mean temperature is 12 °C in this region. Daily precipitation illustrates clear pulse during summer, mainly driven by typhoons (Fig. 1). Chamaecyparis obtusa var. formosana (Hayata) Rehder is the dominant species of this Taiwan cypress forest. As a result of high annual precipitation soils are permanently moist and acidic (i.e. pH <4) (Lin et al. 2011). Although this area is geographically belonged to subtropical zone, this primary montane forest, to some extent, can be analogous to temperate rainforests due to its climatic characteristics.

**Sampling locations**

A slope about 28° next to the lake was divided into three sampling locations, summit, footslope and lakeshore (Fig. 2). The soil at summit is dominantly Albaquult and relatively well drained, whereas the soil at lakeshore is dominantly Histosol and poorly drained due to the frequent immersion by lake water. Footslope, between summit and lakeshore, is dominantly Dystrochrept. The thick layer of organic horizon was derived from Sphagnum across three locations. The depth of organic horizon decreased with an increase in the elevation of the
slope for which the depth of organic horizon for lake-shore, footslope and summit was about 30, 15 and 10 cm respectively. The depth of A horizon was small and ranged between 1 and 5 cm across three locations (Chen and Chiu 2000).

Soil sampling and processing
Five replicates of sampling plots (50 × 50 m each) at each sampling location were evenly chosen along a transect vertical to the slope. After carefully removing undecomposed litter, soil samples at 0–10 cm deep layer (O/A horizon) were collected using a soil auger (8 cm in diameter). The O/A horizon refers to the surface soil which was dominated with organic matter and humus. For lake water samples, each 100 ml water sample was collected from three inlet, one swamp (i.e. shallow) and one lake (i.e. deep) locations (Fig. 2). Three replicates were collected at each location. All samples were brought back to laboratory and kept at 4 °C before analysis. The soil subsamples were air-dried and ground to pass a 2.0 mm sieve for TC and TN analysis.

Laboratory analysis
Soil moisture was determined by oven-dried at 105 °C. The C_{mic} were determined by fumigation extraction method with a conversion factor of 2.22 (Wu et al. 1990). The N_{mic} were estimated from ninhydrin-reactive N released from the biomass and then determined using colorimetrically at 560 nm (Amato and Ladd 1988). Five sets of soil subsamples from each sampling location were incubated at 25 °C and 55 % soil moisture for 7 days for determination of net N mineralisation and net N nitrification rates (Hart and Binkley 1985). For DOC, DON and inorganic N, water extractions were made from all samples. Inorganic nitrogen was determined by using 25 g soil samples with 0.5 M K_{2}SO_{4} extraction, followed by colorimetry flow injection analysis for ammonia and nitrate (FIA; Quikchem-Method-10-107-04-1-L, 1999 and Quikchem-Method-10-107-06-2-A, 1997, respectively). An in-line persulfate digestion followed by FIA in the same auto-analyser was applied in order to determine the concentration of the total dissolved nitrogen, TDN (Quikchem-Method-10-107-04-3-P, 2000). The concentration of the dissolved organic nitrogen (DON) was estimated as difference between TDN and inorganic N. The amount of extractable DOC was evaluated using an Aurora 1030 Wet Oxidation TOC Analyser (O.I. Analytical, USA). TC and TN in soil were analysed by high temperature combustion on a Fisons NA-1500 NCS Analyser (Italy). Water sample was analysed for DON, NH_{4}^{+} and NO_{3}^{-} using the same procedure as soil samples but without extraction processes. All samples were analysed within 2 weeks of sample collection.

Data analysis
Linear mixed-effects models were used to assess the effect of ‘Location’ (i.e. summit, footslope, lakeshore) on the concentration of TC, TN, C_{mic}, N_{mic}, DOC, DON, ammonium, and nitrate for each sampling season. Additionally, linear mixed-effects models were also used to assess the effect of ‘Location’, ‘Season’, and an interactive effect of ‘Location’ and ‘Season’ on soil moisture and soil nutrients across multiple sampling years. Replicate sampling plot (Replication), and replicate sampling plot nested within each sampling year (Year/Replication) were set up as the random effect for former and latter models, respectively. Models used p value calculated based on Satterthwaite’s approximations to indicate the significance of the interested fixed effects. Statistical analyses were carried out using R (R Core Team 2013).

Results
Soil total C and N and microbial biomass
Seasonal concentrations of soil TC, TN, C_{mic}, N_{mic} and the ratio of C_{mic}/TC, N_{mic}/TN, DOC/TC, DON/TN, TC/TN, C_{mic}/N_{mic}, and DOC/DON are presented in Fig. 3. The size of soil TC and TN was high, ranging between 421 and 532 g C kg^{-1} and between 19 and 26 g N kg^{-1}, respectively. Similarly, the size of soil C_{mic} and N_{mic} was also very high, ranging between 1.6 and 4.9 g C kg^{-1}
and between 0.2 and 0.7 g N kg$^{-1}$, respectively. Resulting from very high amount of soil TC and TN, the ratio of soil C$_{mic}$/TC and N$_{mic}$/TN was low, between 0.3 and 1.1 and between 1.0 and 3.5. The ratio of soil DOC/TC and DON/TN was also low, between 0.2 and 0.5 and between 0.1 and 1.3. The ratio of soil TC/TN, C$_{mic}$/N$_{mic}$, and DOC/DON across three topographic locations was between 18.7 and 22.8, between 5.4 and 8.1, and between 5.9 and 9.9, respectively.

Soil moisture and the concentrations of soil DOC, DON, ammonium, and nitrate

Soil moisture levels were always high throughout the year at all topographic locations (Fig. 4). Seasonal concentrations of soil DOC, DON, ammonium and nitrate are presented in Fig. 4. The concentrations of soil DOC and DON were high, ranging from 900 to 1946 mg C kg$^{-1}$ and 90 to 215 mg N kg$^{-1}$. For soil inorganic nitrogen, the concentration of soil ammonium, ranging from 16 to 80 mg N kg$^{-1}$, was higher than nitrate. Soil nitrate, occupying the smallest part of soil inorganic N, ranged from 0.8 to 6.8 mg N kg$^{-1}$.

Soil nitrogen mineralisation and nitrification

The N mineralisation in this forest soil was evident. During a week incubation, the ammonium produced by N mineralisation reached 131 mg N kg$^{-1}$. In contrast, the nitrification (measured as nitrate production during the incubation) was negligible (Fig. 5).

The concentration of DON, ammonium, and nitrate of lake water

The concentration of DON of lake water ranged between 0.77 and 3.37 mg N kg$^{-1}$, and the concentrations of ammonium and nitrate were relatively low compared to the DON (Fig. 6). Thus, organic N was the dominant
Fig. 4 Soil moisture and concentration of dissolved organic C (DOC), dissolved organic N (DON), ammonium, and nitrate of O/A horizon at three topographic locations. Different letters indicate significant difference among locations for a given season ($p < 0.05$)
form of N in lake water for which DON contributed to the high proportion (70–93 %) of the total N in lake water.

**Topographic, seasonal, and interactive effects on soil nutrients**

General speaking, the topographic effect on DOC and DON was not evident, but there were some significant cases over seasons. Surface soils at footslope had slightly higher moisture over seasons (Table 1). The soil DON concentration at footslope was highest over seasons, and that at lakeshore was lowest in winter (Table 1). Surface soils at footslope had the highest ammonium and nitrate concentrations in summer and autumn. Looking at the seasonal pattern, soil moisture was lowest in summer (Table 1). The soil DON concentration was highest in winter and lowest in autumn (Table 1). The ammonium concentration was lowest in summer and the nitrate concentration was lowest in spring, and the ammonium production through net N mineralisation processes was greatest in winter (Table 1).

**Discussion**

The concentration of TC, TN and labile C and N resources

The high liable C and N concentrations in soils might be related to the characteristics of this primary *Chamaecyparis* forest. This primary *Chamaecyparis* forest has accumulated abundant dead woody debris on forest floor (Jien et al. 2010), suggesting a great size of C and N pools in this forest (Gonzalez-Polo et al. 2013; Hafner et al. 2005; Wirth et al. 2009). This may partly explain high soil TC and TN concentrations in this *Chamaecyparis* forest. Long-standing fog immersion has created the suitable environment for epiphytic bryophytes to thrive (Chang et al. 2002), and the cryptogamic cover, such as algae, fungi, lichens and bryophytes, is essential for the C and N cycle in forest ecosystems (Elbert et al. 2012), suggesting that the high amount of organic C and N fluxes might be also associated with the appearance of abundant bryophytes in this primary *Chamaecyparis* forest. A relatively low ratio of $C_{\text{mic}}$/TC and $N_{\text{mic}}$/TN suggests that C and N resources used by microbes were limited in the forest, and this could be due to the low diversity of soil bacterial
communities under the acidic soil environments (Lin et al. 2010), and the constraint of the year-around per-humid environment might also hinder microbial activity and productivity.

The DOC and DON concentrations were profoundly high in the Chamaecyparis forest compared to those in the temperate deciduous forest (DOC: 150–225 mg C kg\(^{-1}\); DON: 35 mg C kg\(^{-1}\)) in Hokkaido, Japan (Shibata et al. 2013) and the temperate coniferous (DON: 7–10 mg C kg\(^{-1}\)) and deciduous forest (DON: 6–7 mg-C kg\(^{-1}\)) in Thuringia forest, Germany (Zhong and Makeschin 2003). The fluxes of DOC and DON in forest floor leachates have been shown to be positively related to the amount of annual precipitation (Michalzik et al. 2001), suggesting that the high fluxes of dissolved organic matter in this Chamaecyparis forest soils might be associated with the high annual precipitation. Additionally, canopy and forest floor have been identified as the important sources of DON, in particular, in pristine ecosystems (Solinger et al. 2001). Schmidt et al. (2010) found that the DOC fluxes (478–962 kg C ha\(^{-1}\) yr\(^{-1}\)) in forest floor leachates were profoundly high and DON (8–16 kg N ha\(^{-1}\) yr\(^{-1}\)) was the major form of total N released from a secondary Chamaecyparis forest near our primary forest. We also observed that the O/A horizon of the Chamaecyparis forest soils contained the great amount of DOC (900–1946 mg C kg\(^{-1}\)), and DON was the dominant forms of N resources, suggesting the existence of high DOC and DON fluxes in this primary forest soil. In addition, we also found that DON being the predominant form of N and in lake water for which DON contributed very high proportions (70–93 %) of total dissolved N. Similarly, this phenomenon was also found in some temperate undisturbed rainforests (Hedin et al. 1995; Perakis and Hedin 2002).

Soil nitrogen mineralisation and nitrification

Compared to DON, ammonium and nitrate concentrations were relatively low at our study forest, but the magnitude was similar to the amount of other forests (Ge et al. 2014; Montaño et al. 2007; Shibata et al. 2013). With negligible amounts of external inputs of ammonium and nitrate (Chang et al. 2002), the most inorganic nitrogen in the forest was the product transformed from organic N. Montaño et al. (2007) demonstrated that the great size of DOC can stimulate heterotrophic microbes and N mineralisation, suggesting that the high ammonium production in this Chamaecyparis forest might be associated with its high C resources. Furthermore, nitrate may be easily lost from soils through direct absorption by plants and leaching processes due to its high mobility, and hence wet environments in such a high rainfall area may also contribute to the low nitrate concentration in surface soils. Immobilisation is one of the important processes in N dynamics. However, the ratio of C/N (i.e. TC/TN) of the O/A horizon was just 20, which was not higher than the critical level of 25 for N immobilisation, the N immobilisation should not be so intense in this forest. Acidity, in particular pH <5.5, has a detrimental effect on the nitrifying bacteria, thus reducing nitrification efficiency (Ste-Marie and Paré 1999). The soil pH was below 4, and the variation of pH was small (i.e. 3.3–3.5) in this

![Fig. 6 Average concentrations of DON, NH4\(^+\) and NO3\(^-\) of the lake water](image-url)
Tsai et al. Bot Stud (2015) 56:27

Chamaecyparis forest soil. This might have an effect on low nitrifying activity and result in low amount of nitrate production.

**Topographic effect and seasonal variation**

Our second hypothesis was not well supported—as the topographic effects on labile C and N and the inorganic N was not consistently evident over seasons. No apparent differences in microbial biomass among soils at various locations suggest that the soil environment of the entire forest across topography was similar. Only few cases in specific seasons could be detected. For example, DON concentrations were relatively low at lakeshore in particular in winter, and this was probably associated with the flooding events which brought organic matter away (Chung et al. 2012). We also observed that soils at footslope had highest inorganic N concentrations in rainy seasons (i.e. summer and autumn), and this might be partly due to the draining environment at footslope where soils can hold more water to increase mineralisation efficiency. The great amount of precipitation and relative warm environments in summer suggests that soils might experience intense dry-wet processes, and this probably stimulated soil microbes to greatly utilise organic N resources in soils. According to previous studies in this area (Chen and Chiu 2000), the detectable migration of humus and top soils from summit to footslope only had marginal effects on the distribution of labile nutrients, suggesting that the topographic effect of humus migration on soil nutrients might not be significant.

**Conclusions**

This subtropical primary montane forest has accumulated the considerable size of DOC in the O/A horizon. DON was the predominant form of total dissolved N resources in soils and lake water. Topographic effects on soil nutrients were not very significant, suggesting that the dynamics of soil nutrient components was relatively equitable across topography, and this may be due to the strong control of per-humid climate and acidic soil conditions. These findings reveal the subtropical primary montane forest soils may hold the great amount of DOC and DON resources, suggesting the importance of this primary montane forest in regional C and N biogeochemical cycles.

**Authors’ contributions**

CWT performed statistical analyses and built statistical models. GT helped in analyzing and interpreting data. CYC originally formulated the idea and

**Table 1** Linear mixed-effects model analysis: the effects of topographic location and seasons on soil moisture, DOC, DON, NH$_4^+$, NO$_3^-$ concentrations, net N mineralisation, and net N nitrification in O/A horizon

| Effects                  | Soil moisture (g g$^{-1}$) | DOC (mg C kg$^{-1}$) | DON (mg N kg$^{-1}$) | NH$_4^+$ (mg N kg$^{-1}$) | NO$_3^-$ (mg N kg$^{-1}$) | Net N mineralisation (mg N kg$^{-1}$ wk$^{-1}$) | Net N nitrification (mg N kg$^{-1}$ wk$^{-1}$) |
|--------------------------|---------------------------|---------------------|----------------------|--------------------------|--------------------------|---------------------------------|---------------------------------|
|                          | Coeff.        | SE       | Coeff.        | SE       | Coeff.        | SE       | Coeff.        | SE       | Coeff.        | SE       | Coeff.        | SE       | Coeff.        | SE       |
| Location                 |              |          |              |          |              |          |              |          |              |          |              |          |              |          |
| Summit$^a$               | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        |
| Footslope                | 0.02*        | 0.01     | NS           | NS       | 35.70*       | 16.78    | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |
| Lakeshore                | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |
| Season                   |              |          |              |          |              |          |              |          |              |          |              |          |              |          |
| Spring$^a$               | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        | 0            | 0        |
| Summer                   | $-0.03^{**}$ | 0.01     | NS           | NS       | NS           | NS       | $-24.20^{***}$ | 6.69    | $-3.62^{***}$ | 0.64    | NS           | NS       | NS           | NS       |
| Autumn                   | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | $-1.65^{*}$ | 0.65    | NS           | NS       | NS           | NS       |
| Winter                   | NS           | NS       | NS           | NS       | 38.04*       | 16.07    | NS           | NS       | $-2.60^{***}$ | 0.61    | 45.83*       | 20.45    | NS           | NS       |
| Interaction              |              |          |              |          |              |          |              |          |              |          |              |          |              |          |
| Footslope × Summer       | NS           | NS       | NS           | NS       | NS           | NS       | 24.63**      | 9.46    | 2.50**       | 0.91    | NS           | NS       | NS           | NS       |
| Lakeshore × Summer       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |
| Footslope × Autumn       | NS           | NS       | NS           | NS       | 31.67***     | 9.34     | 2.02*        | 0.90    | NS           | NS       | NS           | NS       | NS           | NS       |
| Lakeshore × Autumn       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |
| Footslope × Winter       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |
| Lakeshore × Winter       | NS           | NS       | NS           | NS       | $-60.05^{**}$ | 22.86   | NS           | NS       | NS           | NS       | NS           | NS       | NS           | NS       |

Coeff. and SE are the estimated coefficient and standard error of each independent variable in the model

The + or – before the value of Coeff. indicates the higher or lower value than ‘Summit’ in location or ‘Spring’ in season

**p < 0.001, **p < 0.01, * p < 0.05, NS not significant (p > 0.1)

$^a$ Set to zero due to being the standard for comparison within each categorical factor
developed methodology. CWT and CYC wrote the manuscript with inputs from other authors. All authors read and approved the final manuscript.

Author details
1 Biodiversity Research Center, Academia Sinica, Taipei 11529, Taiwan.
2 Environmental Monitoring and Research Division, Monitoring and Research Department, Metropolitan Water Reclamation District of Greater Chicago (MWRD), Lue-Hing R&D Laboratory, 6001 W. Pershing Road, Cicero, IL 60804, USA.

Compliance with ethical guidelines

Competing interests
The authors declare that they have no competing interests.

Received: 9 June 2015   Accepted: 31 August 2015

Published online: 30 September 2015

References

Amato M, Saddin JN (1988) Assay for microbial biomass based on ninhydrin-reactive nitrogen in extracts of fumigated soils. Soil Biol Biochem 20(1):107–114
Chang SC-L, Lai IL, Wu JT-P (2002) Estimation of fog deposition on epiphytic bryophytes in a subtropical montane forest ecosystem in northeastern Taiwan. Atmos Res 64(1–4):159–167
Chen JS, Chiu CY (2000) Effect of topography on the composition of soil organic substances in a perhumid sub-tropical montane forest ecosystem in Taiwan. Geoderma 96:19–30
Chen JS, Chung TL, Tian G, Chiu CY (2013) Characterization of soil organic matter in perhumid natural cypress forest: comparison of humification in different particle-size fractions. Bot Stud 54(1):56
Chung TL, Chen JS, Chiu CY, Tian G (2012) 13C-NMR spectroscopy studies of humic substances in subtropical perhumid montane forest soil. J For Res 17(6):458–467
Core Team R (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna
Elbert W, Weber B, Burnows S, Steinkamp J, Budel B, Andreae MO, Poschl U (2012) Contribution of cryptoendolithic covers to the global cycles of carbon and nitrogen. Nature Geosci 5(7):459–462
Fang Y, Zhu W, Gundersen P, Mo J, Zhou G, Yoh M (2009) Large loss of dissolved organic nitrogen from nitrogen-saturated forests in subtropical China. Ecosystems 12(1):33–45
Galloway JW, Dentener FJ, Capone DG, Boyer EW, Howarth RW, Seitzinger SP, Amato M, Saddin JN (2008) Effects of thinning on leaf-fall and leaf-litter nitrogen concentration in hinoki cypress (Chamaecyparis obtusa Endl.) plantation stands in Japan. For Ecol Manag 255(5–6):1859–1867
Inagaki Y, Kuramoto S, Torii A, Shinomiya Y, Fukushima H (2008) Soil properties and nitrogen utilization of hinoki cypress as affected by strong thinning under different climatic conditions in the Shikoku and Kinki districts in Japan. J For Res 16(5):405–413
Jien SH, Hsu ZY, Iizuka Y, Chen TH, Chiu CY (2010) Geochemical characterization of plasic horizons in subtropical montane forest soils, Northeastern Taiwan. Eur J Soil Sci 61:319–332
Lin YT, Huang YI, Tang SL, Whitman WB, Coleman DC, Chiu CY (2010) Bacterial community diversity in undisturbed perhumid montane forest soils in Taiwan. Microb Ecol 59:369–378
Montaño N, García-Oliva F, Jaramillo V (2007) Dissolved organic carbon affects soil microbial activity and nitrogen dynamics in a Mexican tropical deciduous forest. Plant Soil 295(1–2):265–277
Moore JM, Klosse S, Tabatabai MA (2000) Soil microbial biomass carbon and nitrogen as affected by cropping systems. Biol Fertil Soils 31(3–4):200–210
Neef JC, Asner GP (2001) Dissolved organic carbon in terrestrial ecosystems: synthesis and a model. Ecosystems 4(1):29–48
Parker SS, Hedin LO (2002) Nitrogen loss from South American forests mainly via dissolved organic compounds. Nature 415(6870):416–419
Schmidt BM, Wang CP, Chang SC, Matzner E (2010) High precipitation causes large fluxes of dissolved organic carbon and nitrogen in a subtropical montane Chamaecyparis forest in Taiwan. Biogeochemistry 101(1–3):243–256
Shibata H, Hasegawa Y, Watanabe T, Fukazawa K (2013) Impact of snowpack decrease on net nitrogen mineralization and nitrification in forest soil of northern Japan. Biogeochemistry 116(1–3):69–82
Singh JS, Kashyap AK (2006) Dynamics of viable nitrifier community, N-mineralization and nitrification in seasonally dry tropical forests and savanna. Microbiol Res 161(2):153–226
Ste-Marie C, Paré D (1999) Soil, pH and N availability effects on net nitrification in a Chamaecyparis plantation stands in Japan. For Ecol (Chamaecyparis obtusa Endl.) plantation stands in Japan. For Ecol Manag 255(5–6):1859–1867
Wirth C, Jeimann M, Gleixner G (2009) Old-growth forests: function, fate and value. Ecological Studies, vol 207. Springer, Berlin Heidelberg, Heidelberg, Germany
Wu J, Jørgensen RG, Pomerening B, Chassdod R, Brookes PC (1990) Measurement of soil microbial biomass C by fumigation-extraction—an automated procedure. Soil Bio Biochem 22(8):1167–1169
Zhong Z, Makeschin F (2003) Soluble organic nitrogen in temperate forest soils. Soil Biol Biochem 35(2):333–338