Effects of Short-Term Warming and Precipitation Reduction on Soil DOM Quantity and Spectroscopic Characteristics in Chinese Fir Plantations: Postprint

Authors: Li Huan, Yang Yusheng, Si Youtao, Liu Zhu

Date: 2017-11-09T00:00:00+00:00

Abstract

This study selected soils from Chinese mid-subtropical Chinese fir plantations to conduct short-term warming and 50% rainfall reduction experiments, using spectroscopic techniques to investigate the effects of warming and rainfall reduction on the quantity and structure of soil dissolved organic matter (DOM). The experiment included four treatments: control (CT), warming (W, soil temperature increased by 5°C), rainfall reduction (P, natural rainfall reduced by 50%), and the interaction of warming and rainfall reduction (WP). The results showed: (1) Warming increased the quantity of soil dissolved organic carbon (DOC), decreased the aromaticity index and humification index of DOM, and made the structure simpler and more easily decomposable; soil DOM in the 0-10 cm layer contained more alkanes and fewer ester compounds, while DOM in the 10-20 cm layer contained more carbohydrates. (2) Rainfall reduction caused a relative decrease in soil moisture and reduced the quantity of soil DOC. The aromaticity index and humification degree of soil DOM in the 0-10 cm layer decreased, with DOM containing abundant alkanes; whereas the aromaticity index and humification index of soil DOM in the 10-20 cm layer increased, with fewer carbohydrates. The rainfall reduction treatment increased the quantity of soil dissolved organic nitrogen (DON). (3) The interaction of warming and rainfall reduction increased the quantities of DOC and DON, decreased the aromaticity and humification degree of DOM, caused DOM in the 0-10 cm layer to contain more carbohydrates, while DOM in the 10-20 cm layer had fewer carbohydrates. (4) For the 0-10 cm soil layer, warming had the strongest effect on DOM quantity and structure; as soil depth increased to 10-20 cm, the effect of rainfall reduction became increasingly apparent, and its impact on DOM structure also reached a significant level. Temperature and precipitation are crucial for changes in DOM quantity and chemical structure, and these results

can provide a scientific basis for elucidating the dynamic turnover of soil DOM under global climate change scenarios and predicting future trends in forest soil carbon and nitrogen changes.

Full Text

Effects of Short-Term Global Warming and Precipitation Reduction on the Quantity and Spectral Characteristics of Soil DOM in a Cunninghamia lanceolata Plantation

LI Huan, YANG Yusheng, SI Youtao, LIU Zhu

(College of Geographical Sciences, Fujian Normal University / Key Laboratory for Subtropical Mountain Ecology (Ministry of Science and Technology and Fujian Province Funded), Fuzhou 350007, China)

Abstract

This study investigated the effects of short-term soil warming and 50% precipitation reduction on the quantity and structure of soil dissolved organic matter (DOM) in a Chinese fir plantation in subtropical China using spectroscopic techniques. Four treatments were established: control (CT), warming (W, +5°C soil temperature), precipitation reduction (P, 50% decrease in natural rainfall), and their interaction (WP). The results showed: (1) Warming increased dissolved organic carbon (DOC) content while decreasing the aromaticity and humification indices of DOM, resulting in simpler, more easily decomposable structures. The 0-10 cm soil layer contained more alkanes and fewer esters, whereas the 10-20 cm layer had more carbohydrates. (2) Precipitation reduction decreased soil moisture and DOC content. In the 0-10 cm layer, it reduced aromaticity and humification while increasing alkanes; in the 10-20 cm layer, it enhanced both indices and reduced carbohydrates. Precipitation reduction increased dissolved organic nitrogen (DON) content. (3) The warming × precipitation reduction interaction increased both DOC and DON contents while decreasing aromaticity and humification. The 0-10 cm layer had more carbohydrates, while the 10-20 cm layer had fewer. (4) For the 0-10 cm soil layer, warming had the strongest effect on DOM quantity and structure. As soil depth increased to 10-20 cm, precipitation reduction became more significant, exerting significant effects on DOM structure. Temperature and precipitation are critical drivers of DOM quantity and chemical structure changes. These findings provide scientific basis for elucidating DOM dynamics under global climate change and predicting future trends in forest soil carbon and nitrogen cycling.

Keywords: Cunninghamia lanceolata plantation; soil warming; precipitation reduction; soil dissolved organic matter; aromaticity index; humification degree; spectral characteristics

Introduction

Dissolved organic matter (DOM) is defined as organic matter that can dissolve in water, acids, or alkaline solutions, typically characterized as a continuum of organic molecules passing through a 0.45 m filter [1]. It includes dissolved organic carbon (DOC), dissolved organic nitrogen (DON), and dissolved organic phosphorus (DOP) [1-2]. As an extremely active chemical component in terrestrial ecosystems, DOM sensitively reflects changes in soil organic matter [3] and serves as the most important energy and nutrient source for soil microorganisms, representing a crucial component of terrestrial biogeochemical cycles [2]. DOM also plays a vital role in transporting nutrients from forest ecosystems to aquatic environments [4].

Since the Industrial Revolution, extensive fossil fuel extraction and use have dramatically increased atmospheric "greenhouse gases," altering Earth' s atmospheric composition and biogeochemical cycles and producing climate change characterized primarily by global warming [5]. According to the 2013 IPCC climate change report, global average surface temperature increased by approximately 0.85°C between 1880 and 2012 [6]. Climate warming also causes frequent droughts in terrestrial ecosystems and changes precipitation patterns, with zonal average precipitation likely increasing at high latitudes and some mid-latitude regions but decreasing in subtropical zones [7]. Such changes in terrestrial precipitation patterns have been widely observed globally and regionally [8]. As temperature and moisture are key factors affecting ecosystem processes, global warming and altered precipitation patterns will inevitably affect forest ecosystem structure and function [9-10], first manifesting as changes in forest soil DOM quantity and quality. Therefore, studying soil DOM responses to temperature and moisture is theoretically important for understanding future forest ecosystem carbon and nitrogen cycling.

Current research on temperature and precipitation as single-factor controls has been reported but remains insufficient and controversial. Some studies indicate that DOC quantity increases under warmer climates [11], while MacDonald et al. [12] found no temperature effect on soil DOC, possibly because DOC decomposition and production rates were equivalent. McDowell et al. [13] showed that DON concentration increased with temperature, with higher DON content in summer than winter, whereas other studies found opposite results—higher summer temperatures actually decreased DON concentration due to increased mineralization rates [14]. Soil temperature and moisture are primary factors affecting microbial decomposition of litter and soil organic matter, thereby influencing soil DOM; however, Guggenberger et al. [15] found no moisture effects on soil DOC concentration or composition. These contradictions demonstrate that temperature and moisture effects on soil DOM are extremely complex.

Therefore, establishing multi-factor climate change experimental platforms in typical forest ecosystems to simulate future global climate change and explore temperature and moisture effects on soil DOM is crucial. However, existing field warming platforms are concentrated primarily in mid- to high-latitude regions, with few reports on ecosystem-level field warming combined with multiple climate factors in China' s subtropical regions [16]. China' s humid subtropical zone represents an "oasis" at similar latitudes globally, and due to commercial forest base construction, large areas of evergreen broadleaf forests have been converted to Chinese fir (Cunninghamia lanceolata) plantations, which account for 6.5% of global plantation area [17]. To better understand Chinese fir plantation responses to future climate change, we established a warming and precipitation reduction multi-factor experimental platform in a young Chinese fir plantation, using soil DOM as our research object. Combining UV-Vis spectroscopy, fluorescence spectroscopy (FS), and Fourier transform infrared spectroscopy (FTIR), we examined DOM quantity and chemical structure responses to warming and precipitation changes to deepen understanding of global climate change impacts on forest ecosystem carbon and nitrogen cycling.

Materials and Methods

1.1 Study Site

The experimental site is located at the Sanming Chen' Da State Forestry Farm observation point (26°19 N, 117°36 E) of the Sanming Forest Ecosystem and Global Change Research Station. The site has an average elevation of 300 m, a mid-subtropical monsoon climate, mean annual precipitation of 1,749 mm, mean annual temperature of 19.1°C, and relative humidity of 81%. The soil is red soil developed from biotite granite [18].

1.2 Experimental Design

In 2013, several 2 m × 2 m experimental plots were established. Each plot was isolated by welding four PVC boards (200 cm × 70 cm) to prevent interference between adjacent plots. Soil developed from biotite granite was collected by layers (0–10 cm, 10–20 cm, 20–70 cm), with coarse roots, stones, and other debris removed. The soil was then mixed uniformly by layer and refilled into the plots, with bulk density adjusted using compaction methods to approximate original soil conditions and minimize heterogeneity between plots.

Four treatments were established: control (CT), warming (W), precipitation reduction (P), and their interaction (WP), with three replicates per treatment. In October 2013, heating cables were installed parallel in all plots at 10 cm depth with 20 cm spacing, with an additional cable looped around the perimeter to ensure uniform warming. Warming began five months after cable installation (March 2014), with W and WP plots maintained at 5°C above control soil temperature. For precipitation reduction, transparent U-shaped tubes (0.05 m × 5 m) were installed at 1.5 m height at 5 cm intervals in P and WP plots to intercept 50% of natural rainfall [16]. Four young Chinese fir trees were planted in each plot, positioned between cable lines [Figure 1: see original paper].

1.3 Sample Collection

Sampling was conducted in October 2014. Five soil sampling points were arranged in an S-shaped pattern in each plot, with samples collected by layer (0-10 cm, 10-20 cm). Samples were transported to the laboratory, where debris, gravel, and plant roots were removed. Five subsamples from the same layer in each plot were combined into one composite sample, passed through a 2 mm sieve, with one portion used for basic soil physicochemical property determination and the remainder for DOM extraction.

1.4 Measurements

1.4.1 Soil Basic Physicochemical Properties Soil pH was measured using a CHN868 pH meter (Thermo Orion) at a 2.5:1 water-to-soil ratio. Total soil organic carbon and total nitrogen were determined using a carbon-nitrogen elemental analyzer (VarioMAX, Elementar, Munchen, Germany). Basic soil properties for the four treatments are shown in Table 1 .

1.4.2 Soil DOM Determination Soil DOM was extracted using water extraction [19]. DOC content in the filtrate was measured using a total organic carbon analyzer (TOC-VCPH, Shimadzu, Kyoto, Japan), and DON content was measured using a continuous flow analyzer (San++, Skalar, Breda, Netherlands). UV-Vis absorbance was measured using a UV-Vis spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan). The aromaticity degree of DOM was analyzed by measuring absorbance at 254 nm (Special Ultraviolet-Visible Absorption, SUVA). SUVA, also called aromaticity index (AI), was calculated as AI = (UV254/DOC) × 100 (UV254 is UV absorption at 254 nm) [20].

Fluorescence spectra were measured using a Hitachi F7000 instrument (F7000, Hitachi, Tokyo, Japan) with excitation and emission slit widths of 5 nm and scanning speed of 1,200 nm · min ^{1}. Excitation wavelength was 254 nm with emission wavelength range of 300–480 nm; synchronous wavelength range was 250–500 nm. To improve sensitivity, sample pH was adjusted to 2 with dilute hydrochloric acid before measurement [20]. The humification index (HIX) in synchronous mode was calculated as the ratio of fluorescence intensity at 460 nm to that at 345 nm: HIX = I460/I345 (I460: fluorescence intensity at 460 nm; I345: fluorescence intensity at 345 nm) [20]. HIX represents DOM polymerization degree [21].

For FTIR analysis, 4 mg of freeze-dried sample was ground with 400 mg dried KBr (spectroscopic grade) and pressed into a thin tablet at 10 t · cm ^{2} pressure. FTIR spectra were measured using a Cary 660 FTIR spectrometer with scanning range of 4,000–400 cm ^{1}.

1.5 Data Processing and Analysis

Data were analyzed using SPSS 19.0 software. One-way ANOVA and independent samples t-tests were used to compare differences in soil DOM quantity and spectral characteristics between treatments within the same soil layer and between soil layers within the same treatment. Two-way ANOVA was used to analyze the effects of warming (W) and precipitation reduction (P) factors on DOM quantity and spectral characteristics within the same soil layer ($P < 0.05$). Figures and tables were prepared using Microsoft Excel and Origin.

Results

2.1 Changes in Soil Properties Under Warming, Precipitation Reduction, and Their Interaction

As shown in Table 1 , soil water content in both layers decreased under W, P, and WP treatments compared with CT. Soil pH also decreased under all three treatments, with pH under W and WP significantly lower than non-warmed soils. Within the same treatment, pH in the 10-20 cm layer was higher than in the 0-10 cm layer. In both 0-10 cm and 10-20 cm layers, SOC, STN, and C/N ratios showed decreasing trends under W, P, and WP treatments compared with CT.

2.2 Effects on Soil DOM Quantity

As shown in Figure 2 [Figure 2: see original paper], in the 0-10 cm layer, W and WP treatments increased soil DOC content by 7% and 19%, respectively, while P treatment decreased DOC content compared with CT. In the 10-20 cm layer, DOC content showed similar trends to the 0-10 cm layer, but differences were not significant. For all treatments, DOC content was higher in the 0-10 cm layer than in the 10-20 cm layer. For both layers, soil DON content under W, P, and WP treatments was higher than CT, with greater DON content in the upper layer than the lower layer.

2.3 Effects on UV Spectral Characteristics of Soil DOM

Table 2 shows UV spectral characteristics of soil DOM under the four treatments. In the 0-10 cm layer, AI values under W, P, and WP treatments decreased by 53%, 27%, and 60%, respectively, compared with CT. Two-way ANOVA showed that the W effect was significant (Table 3). In the 10-20 cm layer, AI values under W and WP treatments decreased by 45% and 15%, respectively, while P treatment increased AI by 78% compared with CT. Two-way ANOVA showed that both W and P effects were significant (Table 3). Overall, AI values under CT and W treatments decreased with soil depth, while AI values under P and WP treatments increased with depth, though not significantly.

2.4 Effects on Fluorescence Spectral Characteristics of Soil DOM

Figure 3 [Figure 3: see original paper] shows fluorescence emission spectra of soil DOM under the four treatments. In both 0-10 cm and 10-20 cm layers, the emission wavelength corresponding to the peak shifted to shorter wavelengths after W, P, and WP treatments, with the order being WP < W < P < CT, indicating that CT soil DOM had more complex structures, while W, P, and WP structures were relatively simple.

As shown in Table 2 , in the 0-10 cm layer, HIX values under W, P, and WP treatments were lower than CT, with W and WP significantly decreasing HIX by 50% and 46%, respectively, indicating that CT soil DOM had the highest humification degree. Two-way ANOVA showed that the W effect was significant (Table 3). In the 10-20 cm layer, HIX values under W and WP treatments showed no significant change compared with CT, while P treatment significantly increased HIX. Two-way ANOVA showed that the P effect on HIX was significant (Table 3).

2.5 Effects on FTIR Spectral Characteristics of Soil DOM

Figure 4 [Figure 4: see original paper] shows FTIR spectra of soil DOM under different treatments. The absorption peak near 3,696 cm ^{1} represents N-H stretching vibration. The strong, broad absorption peak in the 3,600-3,200 cm ^{1} range represents hydrogen-bonded hydroxyl stretching vibration, primarily from carbohydrates (cellulose, starch, sugars) as well as alcohols and phenols in DOM samples. The peak near 2,960 cm ^{1} represents asymmetric -CH stretching vibration, while the peak near 2,852 cm ^{1} represents symmetric -CH stretching vibration. The peak near 1,680 cm ^{1} represents C=O stretching vibration. The peak near 1,610 cm ^{1} represents asymmetric stretching vibration of organic carboxylate R-CO and C=O stretching vibration connected to benzene rings in lignin. The peak at 1,383 cm ^{1} represents C-H bending vibration of alkanes. Peaks near 1,149 cm ^{1} and 1,120 cm ^{1} represent C-O stretching vibration of carbohydrates. The 1,033 cm ^{1} peak may represent some esters. The 900-650 cm ^{1} range represents out-of-plane C-H bending vibration of aromatic hydrocarbons [22-23].

In the 0-10 cm layer, the W treatment showed higher relative absorption intensity at 1,383 cm ^{1} but weaker absorption at 1,033 cm ^{1} compared with CT, indicating that warming promoted DOM decomposition and produced large amounts of alkanes. The P treatment showed the strongest absorption peak at 1,383 cm ^{1}, with higher relative proportions than the other three treatments, demonstrating that precipitation reduction also contributed to DOM decomposition, corresponding to decreased aromaticity and humification indices and fewer aromatic compounds in soil DOM compared with CT. The WP treatment showed relatively higher absorption intensity in the carbohydrate region than the P treatment but weaker alkyl absorption than the P treatment, similar to CT, indicating that under the dual-factor interaction, soil DOM condensation degree decreased, aromatic substances decreased, and WP DOM decomposition produced more carbohydrates. Notably, WP showed the most obvious N-H absorption among the four treatments, corresponding to higher DON content.

For the 10-20 cm soil layer, the W treatment showed more carbohydrates at

1,149 cm ^{1} and 1,120 cm ^{1} because warming promoted organic matter decomposition, decreasing DOM aromaticity and humification. The P treatment showed a sharp alkyl absorption peak (1,383 cm ^{1}), indicating that precipitation reduction in this layer produced more alkyl compounds after organic matter decomposition. FTIR absorption was similar between WP and CT. Overall, P and WP treatments contained fewer carbohydrates.

Discussion

DOM is an active component of soil organic matter [3]. This study examined young Chinese fir plantation soil DOM to explore the effects of soil warming and precipitation reduction. For the 0–10 cm layer, warming increased DOC quantity and simplified DOM structure. The aromaticity degree and molecular weight of soil DOM samples are positively correlated with UV absorption SUVA [24-25], while DOM humification degree HIX can describe DOM molecular structure and aromatic compound content [26-27]. The W treatment had the lowest SOC content but highest DOC content, likely because warming alone reduced SOC activation energy and accelerated SOC decomposition [28]. Marilley et al. [29] found that warming can increase microbial biomass carbon (MBC) content, and priming effects can promote SOC decomposition by activating microbial activity to release more extracellular enzymes [30]. FTIR showed that W had greater absorption proportion at 1,383 cm ^{1} but smaller at 1,033 cm ^{1} compared with CT. The 1,383 cm ^{1} absorption originates from alkyl structures, products of mineralization, providing evidence that warming accelerated DOM mineralization. Compared with CT, W showed enhanced relative proportions in the carbohydrate absorption region, consistent with W having the lowest AI and HIX values.

The P treatment alone had the lowest soil DOC quantity and more complex structure than W and WP. Due to reduced moisture, SOC transformation to DOC decreased, and readily decomposable DOC had already been mineralized, resulting in the largest alkyl absorption peak at 1,383 cm ^{1} for P and more complex DOC structure than warmed plots. The SOC decrease under P compared with CT may result from increased autotrophic respiration due to larger soil pores and reduced carbon input from throughfall and root exudates. Prolonged drought limits plant growth by water deficit [31], thereby reducing soil DOC sources. The WP treatment had the highest soil DOC quantity, with SOC content similar to CT. As a dual-factor combination, WP’ s warming activation facilitated SOC-to-DOC transformation, while reduced soil moisture greatly decreased microbial activity and DOC decomposition rate, resulting in the highest DOC quantity. WP also had the lowest AI value, and its FTIR spectrum was most similar to CT, indicating that microbial DOC decomposition activity under WP was significantly lower than under W and P. Two-way ANOVA showed that for 0–10 cm soil, only the W factor significantly affected DOC quantity and structure.

For the 10–20 cm layer, DOC and DON quantities showed similar trends to the upper layer, but DOC structure differed slightly. In this layer, the P treatment had the lowest DOC quantity and most complex structure (significantly different from other treatments), possibly because moisture reduction effects were more pronounced at 10-20 cm depth than in the 0-10 cm surface layer. Reduced moisture was unfavorable for SOC activation to DOC and plant growth, reducing root exudates and resulting in low carbohydrate content in soil DOC and less microbially available carbon. In FTIR, the P treatment in this layer showed stronger 1,383 cm ^{1} absorption than CT. These alkyl structures are not easily utilized by microorganisms and represent decomposition products. Meanwhile, P treatment absorption at 1,033 cm ^{1} decreased, unlike in the 0-10 cm layer where it did not weaken. FTIR data were consistent with AI and HIX values. Due to these P effects, WP treatment also had more complex DOC structure than W treatment. Two-way ANOVA showed that both P and W treatments significantly affected AI and HIX of 10-20 cm soil DOC. However, although P treatment soil DOC was least available to microorganisms, P treatment SOC was relatively low, only higher than W treatment, indicating that SOC under P had also undergone rapid mineralization, with only recalcitrant materials remaining at sampling time.

The P factor had greater influence on DON quantity than the W factor, with P and WP treatments showing the highest DON content. Nitrogen is a nutrient element required for microbial organic matter decomposition. DON accumulation indicates slow microbial mineralization rates, likely due to low-quality carbon substrates. In this study, SOC and STN in both layers were relatively low under P treatment, and microorganisms require both carbon and nitrogen sources for SOC mineralization. Low quality of either carbon or nitrogen will affect microbial mineralization rates.

This study demonstrated through spectroscopic techniques that soil warming can activate SOC to DOC, promote SOC mineralization through priming effects, and transform soils from carbon sinks to carbon sources, decreasing DOM aromaticity and humification indices. Precipitation reduction accelerates SOC mineralization in the short term, reducing SOC content and simplifying DOM structure. However, in later stages, precipitation reduction inhibits microbial activity by reducing substrate availability, resulting in more complex DOC structure with increased aromaticity and humification, while enriching DON. The warming × precipitation reduction treatment had the highest DOM quantity, resulting from combined effects. Under this dual-factor interaction, both aromaticity and humification indices decreased. For 0-10 cm soil, warming had the strongest effect. As soil depth increased to 10-20 cm, moisture reduction effects became more apparent, with precipitation reduction becoming a significant factor affecting DOM structure and the only factor significantly influencing DON quantity.

Temperature and precipitation are crucial for DOM quantity and structural changes. However, field conditions are complex, and other mechanisms also affect DOM dynamics. Only through long-term observations and consideration of other influencing factors can we better understand climate change impacts on soil carbon and nitrogen cycling.

References

[1] Kalbitz K, Solinger S, Park J H, et al. Controls on the dynamics of dissolved organic matter in soils: A review[J]. Soil Science, 2000, 165(4): 277-304

[2] Yang Y S, Guo J F, Chen G S, et al. Origin, property and flux of dissolved organic matter in forest ecosystems[J]. Acta Ecologica Sinica, 2003, 23(3): 547-558

[3] Biederbeck V O, Janzen H H, Campbell C A, et al. Labile soil organic matter as influenced by cropping practices in an arid environment[J]. Soil Biology and Biochemistry, 1994, 26(12): 1647-1657

[4] Bolan N S, Adriano D C, Kunhikrishnan A, et al. Chapter one-dissolved organic matter: Biogeochemistry, dynamics, and environmental significance in soils[J]. Advances in Agronomy, 2011, 110: 1-75

[5] Zhou G S, Wang Y H. Global Ecology[M]. Beijing: Meteorological Press, 2003

[6] Stocker T, Plattner G K, Dahe Q. IPCC climate change 2013: the physical science basis-findings and lessons learned[C]//EGU General Assembly Conference. EGU General Assembly Conference Abstracts. Vienna, Austria: EGU, 2014

[7] Dong S Y, Gao X J. Long-term climate change: Interpretation of IPCC fifth assessment report[J]. Progressus Inquisitiones de Mutatione Climatis, 2014, 10(1): 56-59

[8] IPCC. Climate Change 2007: The Physical Science Basis. Contribution of Working Group to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change[R]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2007

[9] Aronson E L, Mcnulty S G. Appropriate experimental ecosystem warming methods by ecosystem, objective, and practicality[J]. Agricultural and Forest Meteorology, 2009, 149(11): 1791-1799

[10] Melillo J M, Steudler P A, Aber J D, et al. Soil warming and carbon-cycle feedbacks to the climate system[J]. Science, 2002, 298(5601): 2173-2176

[11] Perdue E M, Gjessing E T, Glaze W. Organic Acids in Aquatic Ecosystems: Report of the Dahlem Workshop on Organic Acids in Aquatic Ecosystems, Berlin 1989, May 7-12[M]. Wiley, 1990

[12] MacDonald N W, Randlett D L, Zak D R. Soil warming and carbon loss from a lake states Spodosol[J]. Soil Science Society of America Journal, 1999, 63(1): 211-218

[13] McDowell W H, Currie W S, Aber J D, et al. Effects of chronic nitrogen amendments on production of dissolved organic carbon and nitrogen in forest soils[J]. Water, Air, and Soil Pollution, 1998, 105(1/2): 175-182

[14] Huang W Z, Schoenau J J. Fluxes of water-soluble nitrogen and phosphorus in the forest floor and surface mineral soil of a boreal aspen stand[J]. Geoderma, 1998, 81(3/4): 251-264

[15] Guggenberger G, Zech W. Composition and dynamics of dissolved carbohydrates and lignin-degradation products in two coniferous forests, N.E. Bavaria, Germany[J]. Soil Biology and Biochemistry, 1994, 26(1): 19-27

[16] Liu X F, Lin T W, Xiong D C, et al. Interactive responses of undergrowth vegetation biomass in Chinese fir to soil warming and precipitation separation[J]. Journal of Subtropical Resources and Environment, 2014, 9(3): 92-95

[17] Piao S L, Fang J Y, Ciais P, et al. The carbon balance of terrestrial ecosystems in China[J]. Nature, 2009, 458(7241): 1009-1013

[18] Liu X F, Chen S D, Xiong D C, et al. High-frequency analysis of the diel patterns of soil heterotrophic respiration[J]. Journal of Subtropical Resources and Environment, 2014, 9(1): 92-94

[19] Wu J S, Jiang P K, Chang S X, et al. Dissolved soil organic carbon and nitrogen were affected by conversion of native forests to plantations in subtropical China[J]. Canadian Journal of Soil Science, 2010, 90(1): 27-36

[20] Akagi J, ZsolnayÁ, Bastida F. Quantity and spectroscopic properties of soil dissolved organic matter (DOM) as a function of sample treatments: Air-drying and pre-incubation[J]. Chemosphere, 2007, 69(7): 1040-1046

[21] Zsolnay A, Baigar E, Jimenez M, et al. Differentiating with fluorescence spectroscopy the sources of dissolved organic matter in soils subjected to drying[J]. Chemosphere, 1999, 38(1): 45-50

[22] Kanokkantapong V, Marhaba T F, Panyapinyophol B, et al. FTIR evaluation of functional groups involved in the formation of haloacetic acids during the chlorination of raw water[J]. Journal of Hazardous Materials, 2006, 136(2): 188-194

[23] He X S, Xi B D, Wei Z M, et al. Physicochemical and spectroscopic characteristics of dissolved organic matter extracted from municipal solid waste (MSW) and their influence on the landfill biological stability[J]. Bioresource Technology, 2011, 102(3): 2322-2327

[24] Wang Q Y, Wang Y, Wang Q C, et al. Effects of land use changes on the spectroscopic characterization of hot-water extractable organic matter along chronosequence: Correlations with soil enzyme activity[J]. European Journal of Soil Biology, 2013, 58: 8-12

[25] Scott E E, Rothstein D E. The dynamic exchange of dissolved organic matter percolating through six diverse soils[J]. Soil Biology and Biochemistry,

2014, 69: 83-92

[26] Ohno T. Fluorescence inner-filtering correction for determining the humification index of dissolved organic matter[J]. Environmental Science & Technology, 2002, 36(4): 742-746

[27] Michel K, Matzner E, Dignac M F, et al. Properties of dissolved organic matter related to soil organic matter quality and nitrogen additions in Norway spruce forest floors[J]. Geoderma, 2006, 130(3/4): 250-264

[28] Liu Y, Hu X F, Chen F S, et al. Temperature sensitivity of CO fluxes from rhizosphere soil mineralization and root decomposition in Pinus massoniana and Castanopsis sclerophylla forests[J]. Chinese Journal of Applied Ecology, 2013, 24(6): 1501-1508

[29] Marilley L, Hartwig U A, Aragno M. Influence of an elevated atmospheric CO content on soil and rhizosphere bacterial communities beneath Lolium perenne and Trifolium repens under field conditions[J]. Microbial Ecology, 1999, 38(1): 39-49

[30] Kuzyakov Y, Friedel J K, Stahr K. Review of mechanisms and quantification of priming effects[J]. Soil Biology and Biochemistry, 2000, 32(11/12): 1485-1498

[31] Eamus D. Ecophysiological traits of deciduous and evergreen woody species in the seasonally dry tropics[J]. Trends in Ecology & Evolution, 1999, 14(1): 11-16

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.