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Compositional and chemical characteristics of dissolved organic matter in various types of cropped and natural Chinese soils

Songyan Li[1,2], Meng Li[1*] , Guoxi Wang[2], Xiaolei Sun[2], Beidou Xi[1] and Zhengyi Hu[2*]

Abstract

Background: Exploration of composition and chemical characteristics of soil dissolved organic matter (DOM) is significant to understand its biogeochemical role in terrestrial ecosystems. A total of 43 cropped and 16 natural soils (0–20 cm) under four soil types (cinnamon, chernozem, red and paddy soils) across China were collected to investigate the spectral characteristics of DOM using UV–Vis and 3D-EEM spectroscopy.

Results: The chernozem soils exhibited the highest aromaticity and humification degree among the four soil types. Ranges of biological index (BIX, 0.53–1.17) and fluorescence index (FI, 1.55–2.10) were found in the investigated DOM, showing joint contribution from allochthonous and autochthonous sources. Higher BIX and FI in the DOM of the paddy and red soils indicated a greater reliance on autochthonous sources for these two soil types. The cropped soils showed no significant differences in chemical characteristics and sources from the natural soils for the cinnamon, chernozem and red soils. UVA (16.2–47.9%) and UVC fulvic-like substances (15.4–40.5%) were the prevailing DOM components, which were highest in the chernozem soils. Additionally, the cropped soils had a higher proportion of humic-like substances than the natural soils in the DOM.

Conclusions: Both soil type and land-use strongly affected the chemical characteristics of soil DOM, but only soil type had an impact on the DOM composition for the collected soils. These findings may contribute to the prediction of the biochemical behavior of soil DOM under different soil types and land-uses in terrestrial ecosystems.

Keywords: Water-soluble organic matter, Land-use, Soil type, Three-dimensional excitation–emission matrix fluorescence (3D-EEM) spectroscopy, Parallel factor analysis (PARAFAC), Spectral indices

Background

Soil dissolved organic matter (DOM) is a mixture of various soluble organic compounds, which are mainly derived from terrestrial and autochthonous sources [1], including soluble substances in decaying root and leaf, root exudates, leaching or decomposition of older soil organic matter (SOM) and microbial metabolism [2]. Despite its small content in soil, DOM is the most reactive fraction of organic matter in soils and plays a

significant role in the terrestrial biogeochemical cycles [3–5]. Generally, soil DOM is comprised of humic-, tyrosine- and fulvic-like substances, phenolic compounds, carbohydrates, polysaccharides and N-containing molecules derived from protein and chitin [6, 7]. Due to its complex structure, DOM has been regarded as a binding hot spot for heavy metals and organic pollutants, affecting the transportation and fate of soil contaminants [8–10]. Moreover, many studies have reported discrepant effects of variant chemical functional groups, compositional structures and sources of DOM on the fate and transportation of heavy metals in soil [11–13]. Fest et al. [14] showed that high-molecular-size fractions promoted the combination of DOM with heavy metals. However, the enhancement of DOM with condensed

*Correspondence: limeng12b@mails.ucas.ac.cn; zhyhu@mail.ucas.ac.cn
[1] State Environmental Protection Key Laboratory of Simulation and Control of Groundwater Pollution, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
[2] Sino-Danish College, College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

Li *et al. Chem. Biol. Technol. Agric.*   (2019) 6:20

Page 2 of 11

humic substances has been proposed to suppress metal transportation [15]. Therefore, it is significant to explore the composition and chemical characteristics of DOM in soil to understand its biogeochemical role.

Many researches have focused on the influence of land-use and soil type on the chemical properties, sources and composition of soil DOM [16, 17]. Chantigny et al. [18] reported a lower DOM concentration in the cultivation soils than in the forest and grassland soils. Some studies also observed varied chemical properties and compositions of DOM under different land-uses, especially when comparing the natural and cropped lands [19, 20]. Additionally, Gao et al. [1] found that the DOM in chestnut and red soils had higher aromaticity than in other soils such as chernozem and cinnamon soils. Wang et al. [21] also reported that DOM of a clayey soil showed a remarkably higher aromaticity and hydrophobicity than the DOM of a sandy soil. Therefore, we hypothesized that the chemical characteristics and composition of soil DOM may be affected by the land-uses and the soil types.

The objective of this study was thus to identify the chemical characteristics, sources and composition of DOM extracted from soils across China under different land-uses (natural and cropped land) and soil types (chernozem, cinnamon, red and paddy soils) using ultraviolet–visible (UV–Vis) and three-dimensional excitation–emission matrix fluorescence (3D-EEM) spectroscopy.

Methods

Soil collection
A total of 16 natural and 43 cropped surface soils (0–20 cm) were collected from 59 sampling sites across 19 provinces of China (Additional file 1: Table S1). Sites of four soil types (chernozem, number of samples (n) = 16; red, n = 11; cinnamon, n = 14; and paddy soil, n = 18) and two land-uses (native and cropped land) were selected as sampling locations. Maize (*Zea may* L.), zucchini (*Cucurbita pepo* L.), oilseed rape (*Brassica campestris* L.) and rice (*Oryza sativa* L.) were grown in the croplands, while the natural lands were mainly forest and grasslands. Detailed climatic, vegetation and sampling information is given in Additional file 1: Table S1. Three soil samples were collected from each sampling site and thoroughly mixed into one sample. The soils were then transported to the laboratory immediately. The samples were freeze-dried after removing roots and gravel and then ground to pass through 2- and 0.15-mm nylon sieves.

Soil characterization and DOM extraction
Soil pH was measured with a S20K pH meter (Mettler Toledo, Switzerland) in a soil/water ratio of 1:2.5. SOM content was determined by the wet H_2SO_4–$K_2Cr_2O_7$ oxidation method [22]. Cation-exchange capacity (CEC) was detected using the ammonium acetate (NH_4COOH) method [23]. An elemental analyzer (Elementar, Germany) was used to determine the total nitrogen (TN) and carbon (TC) in the soils. The contents of dissolved organic carbon (DOC) and nitrogen (DON) were measured by the method described by Jones and Willett [24].

The extraction of soil DOM was performed referring to a simply modified method described by Gao et al. [1]. In brief, 4 g of freeze-dried soil was mixed with deionized water with a soil/water ratio of 1:10 in a 50-ml centrifuge tube. The mixture was shaken under N_2 environment at 25 °C for 18 h and then centrifuged at 8000g and 25 °C for 20 min. After a filtration through a 0.45-μm glass fiber filter, the solution of DOM was obtained and stored at − 20 °C until analysis.

UV–Vis and 3D-EEM spectroscopy
In order to avoid inner-filter effects on fluorescence and UV–Vis analysis, the concentrations of total organic carbon (TOC) in the DOM solutions were uniformly diluted to 10 mg/l prior to determination [25]. UV–Vis spectra of the DOM sample in a 1-cm quartz cuvette were recorded on a UV-2802 spectrometer (UNICO, UK) with a scanning wavelength of 254 nm. Deionized water was used as a measurement blank for the UV–Vis spectral analysis. SUVA$_{254}$ was calculated by dividing the UV absorbance at wavelength of 254 nm by the DOC concentration to indicate the relative contents of aromatic compounds [26].

A F7000 fluorescence spectrometer (Hitachi, Japan) was employed to create EEMs for the DOM samples based on measurement of fluorescence intensity at emission wavelengths ranging from 200 to 480 nm and excitation wavelengths ranging from 200 to 450 nm. The fluorescence spectra were scanned with a slit width of 5 nm and a scanning speed of 2400 nm/min. Parallel factor analysis (PARAFAC) was applied using the DOMFluor toolbox on MATLAB R2016a (Mathworks, USA) to identify outlier and eliminate the Raman scattering effect on the EEM spectra [27]. Residual and split-half analyses were further conducted to validate fluorescence components of DOM [28]. Spectral indices were calculated from the fluorescence EEMs, following the previously reported definitions for fluorescence index (FI) [29], biological index (BIX) [30] and humification index (HIX) [31]. In brief, FI and BIX were calculated by the ratios of fluorescence intensity at emission wavelengths of 470 nm and 520 nm (excitation wavelength of 370 nm) and at emission wavelengths of 380 nm 430 nm (excitation wavelength of 310 nm), respectively [29]. HIX was defined as the inner-filter corrected fluorescence intensity in the 435–480-nm region divided by the sum of fluorescence intensity in

Li *et al. Chem. Biol. Technol. Agric.* (2019) 6:20

Page 3 of 11

the regions of 300–345 nm and 435–480 nm [31]. HIX has been widely employed to indicate the humification index in DOM [26, 32]. FI is typically used to distinguish the autochthonous (FI > 1.9) and from allochthonous (FI < 1.4) sources of DOM [29], while BIX reflects on recently produced autochthonous (biological) DOM [33].

Data statistics

One-way analysis of variance (ANOVA) was performed using SPSS v24.0 (IBM, USA) to test the significant differences in soil physicochemical properties and spectral characteristics of DOM under different land-uses and soil types. Correlations of soil properties with spectral indices and fluorescence components of DOM were conducted using SPSS v24.0 (IBM, USA). Two-way ANOVA was employed using SPSS v24.0 (IBM, USA) to investigate the effects of soil types and land-uses on the spectral indices and fluorescence components in the DOM. A redundancy analysis (RDA) was performed with XLSTAT v2012 software (Addinsoft, USA) to detect the multivariate relationships among soil properties, spectral indices and DOM components.

Results

Soil properties

Soil pH ranged from 4.47 to 9.18 with an average of 6.52 (Table 1). The cinnamon (7.96 ± 0.89) and chernozem soils (7.82 ± 0.80) had higher pH than the red (6.44 ± 1.49) and paddy soils (6.71 ± 1.17). No significant difference in soil pH in between natural and cropped soils was found. The SOM content was $4.07\% \pm 1.51\%$ with the highest SOM detected in the chernozem soils ($6.61\% \pm 3.38\%$). The SOM content in the natural soils was higher than in the cropped soils (Table 1). The CEC in the soils was 28.60 cmol/kg on average with a range from 6.23 to 49.25 cmol/kg, while the chernozem soils had the highest CEC (32.12 ± 8.28 cmol/kg). A range of soil TN from 0.04 to 0.58% was detected with higher TN in the cropped soils than in the natural soils. TC content for all the soils ranged from 0.33% to 7.95% with an average of 1.86%. No significant differences in TN, TC and TC/TN ratio were found in between the four soil types (Table 1). The DOC and DON were 0–0.36 mg/g and 0–0.05 mg/g in all the soils with a DOC/DON ratio ranging from 1.4 to 16.3. The paddy soils had the lowest DOC (0.08 ± 0.08 mg/g) and DON (0.01 ± 0.01 mg/g).

UV–Vis and 3D-EEM spectroscopy

As calculated from UV–Vis spectra for the DOM samples, $SUVA_{254}$ values ranged from 0 to 3.1 with an average of 1.49 (Table 2). The highest and lowest $SUVA_{254}$ were found in the DOM of the chernozem (2.03 ± 0.48)

and paddy soils (1.10 ± 0.54), respectively. HIX index was found to be 0.77 ± 0.10 in the DOM samples. The DOM of the chernozem (0.92 ± 0.02) and cinnamon soils (0.86 ± 0.03) possessed the higher HIX index than that of the paddy (0.79 ± 0.05) and red soils (0.75 ± 0.14). The spectral indices of BIX and FI for all the soil DOM were 0.61–1.17 and 1.55–2.10, respectively. The BIX and FI of the DOM in the chernozem and cinnamon soils were significantly ($P < 0.05$) lower than in the red and paddy soils. Very few DOM samples had FI exceeding 1.9 and BIX higher than 1.0. No significant differences in spectral indices were found in between the natural and the cropped soils (Table 2).

As shown in Fig. 1, five fluorescence components (C1–C5) were identified by the PARAFAC of all the DOM samples and assigned to be: UVA fulvic-like substances (C1, Ex/Em = 265/460 nm) [27, 28], UVC fulvic-like substances (C2, Ex/Em = 230/400 nm) [34], humic-like substances (C3, Ex/Em = 320 (250)/400 nm) [35, 36], tryptophan-like substances (C4, Ex/Em = 230 (275)/330 nm) [37] and peptide-like compounds (C5, Ex/Em = 220/330 nm) [1, 4, 38].

C1 (16.2%–47.9%) and C2 (15.4%–40.5%) were the prevailing fluorescence components in the DOM (Fig. 2), while C5 was the lowest component accounting for 0–24.7%. The chernozem soils had the highest proportion of C1 (36.3%–47.9%) and the lowest proportion of C4 (3.7%–14.3%), while the red soils possessed the highest and lowest proportions of C3 (13.6%–23.7%) and C5 (0–7.5%), respectively. Higher proportion of C4 and lower proportion of C2 were observed in the red and paddy soils than in the chernozem and cinnamon soils (Fig. 2). The cropped chernozem and red soils had higher proportion of C1 and C3 but lower proportion of C4 than the natural soils. As for the cinnamon soils, the cropped soils occupied higher shares of C2 (21.6%–40.5%) and C3 (10.8%–13.6%) in the total DOM than the natural soils (28.4%–30.6% for C2 and 8.1%–10.4% for C3).

Relationship of DOM composition and spectral indices with soil properties

DOC and SOM were significantly positively ($P < 0.01$) correlated with $SUVA_{254}$ in the soil DOM but negatively correlated with the BIX and FI (Fig. 3). No significant correlations of the TC, TN and CEC with spectral indices were found. Among the spectral indices for the DOM samples, $SUVA_{254}$ and HIX possessed significantly negative correlations with BIX and FI, while $SUVA_{254}$ had a positive relationship with HIX. FI and BIX showed negative correlations ($P < 0.01$) with the proportions of C1 and C2 and positive correlations ($P < 0.01$) with the proportions of C3 and C4 in the DOM (Fig. 3). Conversely,

Table 1 Soil properties of 59 soils of four soil types under two land-uses (natural land and cropped land) across China

Items	n	pH	SOM/%	DOC/mg/g	DON/mg/g	DOC/DON	CEC/cmol kg^{-1}	TN/%	TC/%	TC/TN
All soils	59	6.52±1.34	4.07±1.51	0.09±0.09	0.02±0.01	7.0±3.6	28.60±7.42	0.19±0.09	1.86±1.28	11.9±9.2a
Chernozem soils	16	7.82±0.80a	6.61±3.38a	0.16±0.05a	0.02±0.01a	7.2±3.3a	32.12±8.28a	0.17±0.08a	1.69±1.26a	10.8±9.5a
Natural	7	7.57±0.99	9.45±3.18*	0.18±0.03	0.03±0.01	5.0±1.7	33.96±9.84	0.15±0.10*	1.70±1.92	8.4±2.6
Cropped	9	8.01±0.62	4.40±1.16*	0.15±0.06	0.02±0.01	9.8±2.9	32.91±8.72	0.16±0.05*	1.67±0.45	14.0±14.0
Cinnamon soils	14	7.96±0.89a	3.39±2.50b	0.11±0.02ab	0.03±0.01a	4.6±2.3b	23.03±8.90b	0.21±0.07a	2.71±1.84a	15.7±14.5a
Natural	5	8.67±0.43	4.03±3.81*	0.12±0.02	0.03±0.01	3.9±1.7	17.46±9.70*	0.14±0.06*	3.63±2.56	27.1±19.8
Cropped	9	7.56±0.83	2.59±1.67*	0.11±0.02	0.02±0.01	5.9±2.9	21.67±9.01*	0.29±0.22*	2.20±1.17	9.4±4.5
Paddy soils	18	6.71±1.17b	3.92±1.55b	0.08±0.08b	0.01±0.01b	9.0±2.8a	25.96±6.93ab	0.22±0.13a	2.66±1.76a	12.2±4.0a
Red soils	11	6.44±1.49b	4.06±1.73b	0.12±0.11ab	0.02±0.02a	6.5±4.8a	27.60±9.60a	0.16±0.13a	1.84±1.5a	8.3±4.1a
Natural	4	5.01±0.73	5.46±1.48*	0.10±0.10*	0.03±0.02	6.2±5.6	26.54±11.85*	0.08±0.05*	0.84±0.46	9.0±4.4
Cropped	7	7.25±1.14	3.26±1.54*	0.13±0.12*	0.02±0.02	7.1±3.6	29.44±4.39*	0.21±0.14*	2.41±1.68	6.9±3.8

The value was given by mean ± standard error. Different letters represent significant differences in soil properties between soil types

n number of samples, *SOM* soil organic matter, *DOC* dissolved organic carbon, *DON* dissolved organic carbon, *CEC* cation-exchange capacity, *TN* total nitrogen, *TC* total carbon

* Indicates significant difference in soil properties between natural and agricultural soils at $P < 0.05$ level

Li *et al. Chem. Biol. Technol. Agric.*　　(2019) 6:20

Page 5 of 11

Table 2 Spectral indices of DOM extracted from 59 soils of four soil types under two land-uses (natural land and cropped land) across China

Items	n	SUVA$_{254}$	HIX	BIX	FI
All soils	59	1.49 ± 0.68	0.77 ± 0.10	0.79 ± 0.14	1.73 ± 0.15
Chernozem soils	16	2.03 ± 0.48a	0.92 ± 0.02a	0.60 ± 0.05b	1.60 ± 0.06b
Natural	7	1.99 ± 0.32	0.91 ± 0.01	0.59 ± 0.05	1.63 ± 0.04
Cropped	9	2.05 ± 0.60	0.92 ± 0.03	0.61 ± 0.04	1.57 ± 0.07
Cinnamon soils	14	1.52 ± 0.64ab	0.86 ± 0.03a	0.66 ± 0.06b	1.69 ± 0.06b
Natural	5	1.24 ± 0.14	0.85 ± 0.03	0.70 ± 0.07	1.68 ± 0.06
Cropped	9	1.67 ± 0.76	0.87 ± 0.03	0.64 ± 0.03	1.71 ± 0.04
Paddy soils	18	1.10 ± 0.54b	0.79 ± 0.05b	0.77 ± 0.11a	1.81 ± 0.14a
Red soils	11	1.29 ± 0.72b	0.75 ± 0.14b	0.88 ± 0.19a	1.88 ± 0.16a
Natural	4	1.59 ± 0.74	0.70 ± 0.08	0.77 ± 0.08	1.91 ± 0.15
Cropped	7	1.12 ± 0.71	0.78 ± 0.16	0.84 ± 0.16	1.83 ± 0.17

The value was given by mean ± standard error. Different letters represent significant differences in DOM spectral indices between soil types

n number of samples, *HIX* humification index, *FI* fluorescence index, *BIX* biological index

soil pH and the HIX of DOM were positively correlated ($P < 0.01$) with the proportions of C1 and C2 and negatively correlated ($P < 0.01$) with the proportion of C4.

The RDA plot reported in Fig. 4 reveals multiple relationships among soil properties, spectral indices and fluorescence components of the soil DOM. The axes of RD1 and RD2 explained 60.27% and 32.24% of the total variation, respectively. Along the RD1, a net differentiation of the paddy soils from the cinnamon and chernozem soils was detected and ascribed to the different DOM compositions. Additionally, the natural soils for the chernozem, red and cinnamon soils were neatly separated from the cropped soils of these three soil types along the RD1. Along the RD2, a distinct separation of the red soils from the other three types of soils was observed. Two-way ANOVA showed a significant effect ($P < 0.001$) of soil types on the spectral indices and the fluorescent components of the DOM (Table 3). Land-uses (cropped and natural land) and its intercept with soil types did not significantly affect ($P > 0.05$) the spectral indices, but had an impact on the fluorescence components of C1, C4 and C5.

Discussion
Effect of soil types on the spectral characteristics of soil DOM
Most of the collected chernozem and cinnamon soils were alkalic, whereas a majority of the red and paddy soil samples showed weak acidity (Table 1). These results are in line with previous studies [39, 40]. It has been proposed that the chernozem soils had higher SOM abundance than the cinnamon, red and paddy soils on a countrywide scale [41], which was also observed in the present study. Lower input of organic matter and stronger decomposition of SOM may contribute to the lower SOM in the cropped soils than in the natural

soils (Table 1) [42]. Higher CEC and TN detected in the cropped soils than in the natural soils may be due to fertilization during the cropping management [43, 44]. The range of the DOC content in the investigated soils was in line with previous studies [1, 45].
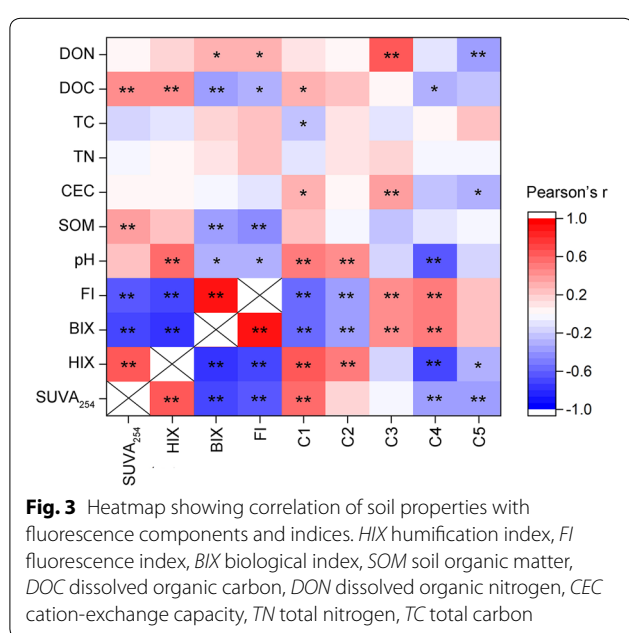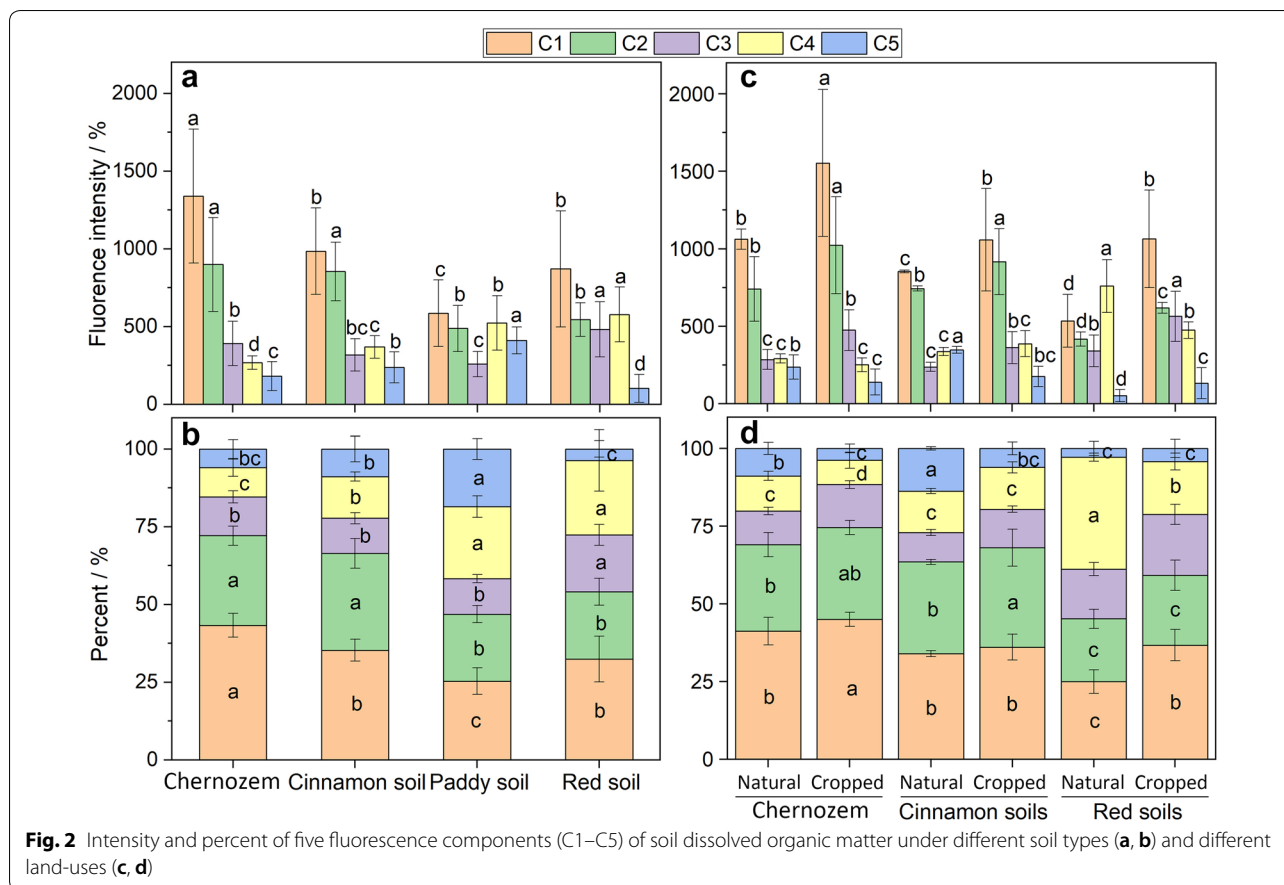
Among the four soil types, the DOM extracted from the chernozem soils possessed the highest SUVA$_{254}$ and HIX, showing the highest degrees of aromaticity and humification (Table 2). By contrast, the lowest SUVA$_{254}$ and HIX were detected in the DOM from the paddy and red soils and indicated the lowest aromaticity and humification degrees. A previous study has also reported a higher aromaticity in several chernozem soils than in the red soils [1]. This may be attributed to the higher SOM found in the chernozem soils than in the paddy and red soils (Table 1), and the decomposition and humification of SOM may induce an accumulation of aromatic compounds in the chernozem soils [46]. Additionally, positive correlations of HIX and SUVA$_{254}$ with DOC (Fig. 3) may hint that DOC served as a significant C source for the growth of soil microbiome and favored the decomposition and humification of SOM in soil [6, 47]. FI and BIX of the soil DOM were mainly distributed in the ranges of $1.4 < FI < 1.9$ and $0.6 < BIX < 1.0$ (Table 2) and suggested a joint contribution of DOM from microbial and allochthonous sources [7, 48]. The DOM of the paddy and red soils had lower BIX and FI than that of the chernozem and cinnamon soils, showing greater autochthonous sources which may be due to stronger microbial activity [49]. BIX had a positive relationship with FI ($P < 0.01$, Fig. 3), which is in line with a previous study of Jiang et al. [7]. In general, SUVA$_{254}$, BIX, HIX and FI of the DOM varied with different soil types (Table 2). In addition, the two-way ANOVA also suggested a strong effect of soil types on the spectral indices of the soil DOM (Table 3).
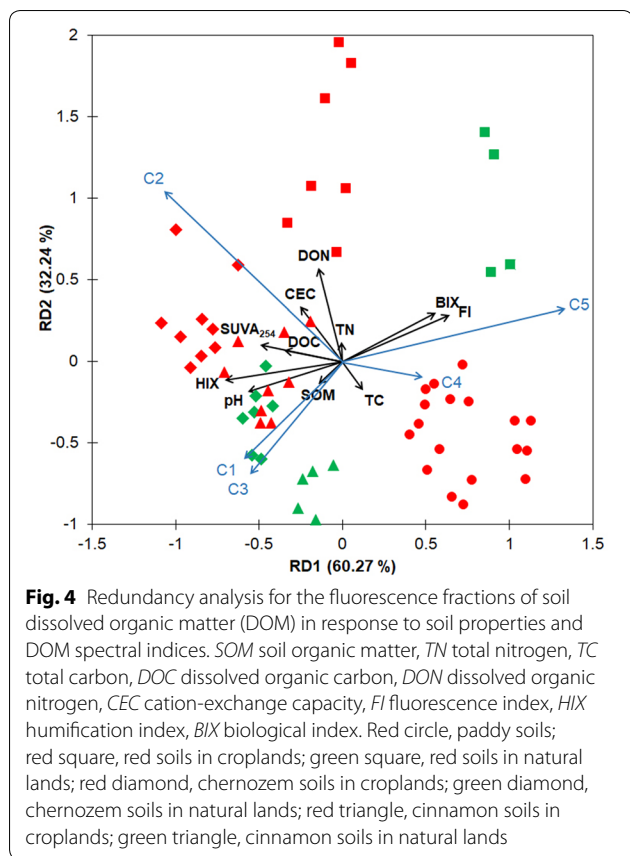
Li *et al. Chem. Biol. Technol. Agric.*   (2019) 6:20

Page 6 of 11
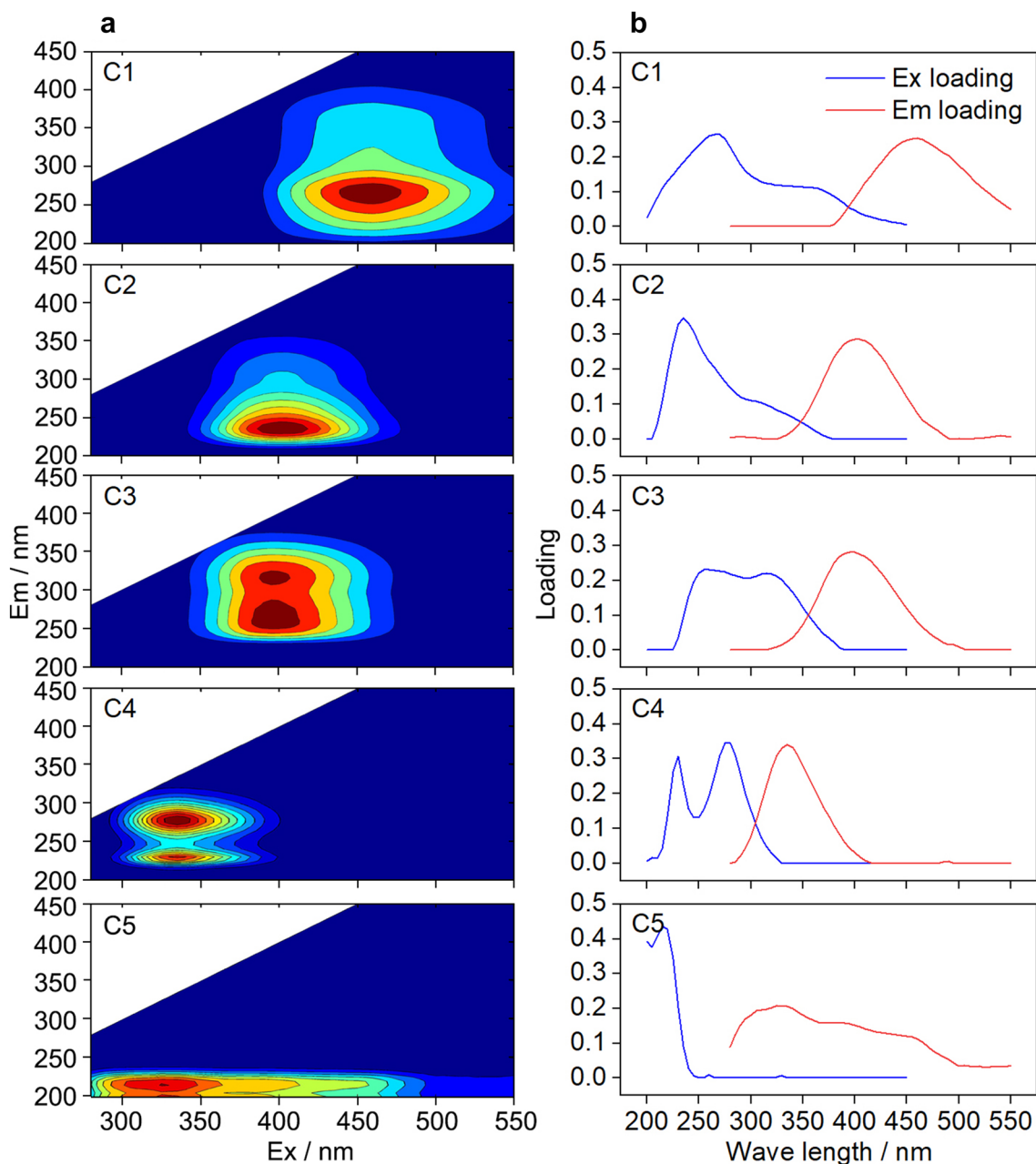
Fig. 1 Spectra (**a**) and loading (**b**) of fluorescence components (C1–C5) of soil dissolved organic matter by EEM spectroscopy and parallel factor analysis

Despite a wide range of soil physicochemical properties (Table 1), fulvic-like substances were the prevailing fluorescence components in the soil DOM, which is in line with a previous study of Ren et al. [50]. As shown in Fig. 2, various soil types had different distributions of DOM fluorescence components in the collected soils. The chernozem and cinnamon soils possessed higher proportion of UVA (C1) and UVC (C2) fulvic-like substances, which have been proposed to be mainly derived from allochthonous sources [34]. Meanwhile, tryptophan-like substances (C4) in the DOM were thought to be mainly derived from autochthonous sources [36] and were positively correlated with BIX and FI in the present study (Fig. 3). The proportion of tryptophan-like substances in the DOM were lower in the chernozem and cinnamon soils than in the paddy and red soils (Fig. 2b), therefore

Li *et al. Chem. Biol. Technol. Agric.*   (2019) 6:20

Page 7 of 11

Fig. 2 Intensity and percent of five fluorescence components (C1–C5) of soil dissolved organic matter under different soil types (**a**, **b**) and different land-uses (**c**, **d**)

Fig. 3 Heatmap showing correlation of soil properties with fluorescence components and indices. *HIX* humification index, *FI* fluorescence index, *BIX* biological index, *SOM* soil organic matter, *DOC* dissolved organic carbon, *DON* dissolved organic nitrogen, *CEC* cation-exchange capacity, *TN* total nitrogen, *TC* total carbon

indicating a relatively low DOM contribution from autochthonous sources. This is in accord with the lower BIX and FI (Table 2) detected in the DOM of the chernozem and cinnamon soils. The red soils exhibited the highest relative abundance of humic-like substances (C4, Fig. 2b), which may be explained by the fact that the red soils were often Fe-rich and the complexation of Fe with DOC may suppress the decomposition of humic substances [51]. The paddy soils had the highest proportion of peptide-like substances (C5), which are usually considered as autochthonous and represent the magnitude of the biological and microbial activities [35]. It is worth noting that the two-way ANOVA showed a great effect of the soil types on the DOM composition (Table 3). The RDA plot also revealed that the fluorescence components of the DOM were strongly affected by the sources and chemical characteristics of the DOM and the soil properties for different soil types (Fig. 4).

Li *et al. Chem. Biol. Technol. Agric.*　　(2019) 6:20

Page 8 of 11

Fig. 4 Redundancy analysis for the fluorescence fractions of soil dissolved organic matter (DOM) in response to soil properties and DOM spectral indices. *SOM* soil organic matter, *TN* total nitrogen, *TC* total carbon, *DOC* dissolved organic carbon, *DON* dissolved organic nitrogen, *CEC* cation-exchange capacity, *FI* fluorescence index, *HIX* humification index, *BIX* biological index. Red circle, paddy soils; red square, red soils in croplands; green square, red soils in natural lands; red diamond, chernozem soils in croplands; green diamond, chernozem soils in natural lands; red triangle, cinnamon soils in croplands; green triangle, cinnamon soils in natural lands

Effect of land-use on the spectral characteristics of soil DOM

For the DOM spectral indices of SUVA$_{254}$, HIX, FI and BIX, no significant ($P > 0.05$) differences were found in between the natural and the cropped soils (Table 2). This was confirmed by the two-way ANOVA, which showed

that no significant ($P > 0.05$) effect of land-use on the spectral indices of the DOM was detected (Table 3). However, it has been reported by previous studies [16] that the cropped soils exhibited distinct differences in humification, aromaticity and sources of the DOM from the natural soils. The great spatial variability of chemical characteristics and sources of the DOM in a large scale may contribute to the discrepant results from the present study.

In comparison with the cropped soils, the natural soils possessed higher proportion of UVA and UVC fulvic-like and humic-like substances in the DOM for the chernozem, cinnamon and red soils (Fig. 2c, d). This is in line with Zhang et al. [52] showing that more fulvic- and humic-like compounds are detected when the land-use is changed from natural land to farmland. In contrast, the DOM of the natural chernozem soils had higher proportions of tryptophan- and peptide-like substances than the cropped chernozem soils. A higher proportion of peptide-like substances in the cropped cinnamon soils and a higher proportion of tryptophan-like substances in the cropped red soils were also found in comparison with the corresponding natural soils. This may be due to a lower input and a faster decomposition of the SOM in the cropped soils [53, 54]. The removal of above-ground biomass of crops by harvesting reduced the input of plant residues, and therefore, DOM in the cropped soil relied more on allochthonous sources [16]. Organic amendments, such as straw application, use of manure and organic conditioners, may alter the composition and characteristics of DOM [20, 33]. Conversely, more easily decomposed litter and roots entered the natural soils and improved the microbial activity to accelerate SOM transformation which could accumulate more microbial metabolites, such as peptide- and tryptophan-like

Table 3 Effects of soil types and land-uses on the spectral indices and fluorescence components in the DOM as evaluated by two-way ANOVA

	Soil types (*T*)		Land-uses (*L*)		*T* × *L*	
	F	*P*	*F*	*P*	*F*	*P*
SUVA$_{254}$	6.17	0.001	0.00	0.974	1.81	0.174
HIX	18.92	< 0.001	3.52	0.066	0.89	0.417
BIX	12.42	< 0.001	0.46	0.502	2.24	0.116
FI	13.69	< 0.001	1.11	0.297	1.08	0.349
C1	66.95	< 0.001	20.88	< 0.001	4.72	0.013
C2	24.87	< 0.001	3.06	0.086	0.04	0.963
C3	53.58	< 0.001	35.91	< 0.001	0.13	0.875
C4	154.16	< 0.001	77.55	< 0.001	43.09	< 0.001
C5	111.40	< 0.001	20.36	< 0.001	9.17	< 0.001

C1–C5, fluorescence components identified from the DOM samples

HIX humification index, *FI* fluorescence index, *BIX* biological index

Li *et al. Chem. Biol. Technol. Agric.*   (2019) 6:20

Page 9 of 11

substances [38]. For the cinnamon, chernozem and red soils, the RDA also showed a neat separation of the cropped soils from the natural soils, indicating an important impact of land-uses on the DOM compositions. The two-way ANOVA revealed that most of the soil DOM components were affected by land-use and land-use × soil type.

Conclusions

Here, we conducted spectral analyses of the soil DOM extracted from 59 natural and cropped soils across China under four different soil types to investigate the chemical characteristics, sources and composition of DOM. The results showed that DOM of the chernozem and cinnamon soils exhibited the highest aromaticity and humification degree. Allochthonous and autochthonous sources jointly contributed to the DOM from the investigated soils; however, the DOM in the paddy and red soils was derived more from autochthonous sources. The cropped soils showed no significant differences in chemical characteristics and sources from the natural soils for the cinnamon, chernozem and red soils. UVA and UVC fulvic-like substances were the prevailing fluorescence components in the DOM samples. The DOM of the chernozem soils had the highest proportions of UVA and UVC fulvic-like substances, while the DOM of red soils possessed the highest humic- and tryptophan-like substances. In contrast to the natural soils, the cropped soils had higher proportion of humic-like substances but a lower proportion of tryptophan-like substances in their DOM. RDA and two-way ANOVA showed that soil types and land-use strongly affected the chemical characteristics of the soil DOM, but soil types had also an impact on the DOM composition. The findings of this study prove the heterogenous nature of the corresponding DOM under various soil types and land-uses. Only by taking in account DOM variability may we deepen our knowledge in order to predict the biochemical behavior of soil DOM in the terrestrial ecosystems to prevent the losses of soil fertility and to avoid soil pollution from spreading.

Additional file

Additional file 1: Table S1. Soil collection (surface soil, 0–20 cm, $n = 59$) from natural lands and croplands across China.

Abbreviations
DOM: dissolved organic matter; UV–Vis: ultraviolet–visible; 3D-EEM: three-dimensional excitation–emission matrix fluorescence; BIX: biological index; FI: fluorescence index; PARAFAC: parallel factor analysis; CEC: cation-exchange capacity; TN: total nitrogen; TC: total carbon; DOC: dissolved organic carbon; DON: dissolved organic nitrogen; TOC: total organic carbon; HIX: humification index; ANOVA: analysis of variance; RDA: redundancy analysis.

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Li *et al. Chem. Biol. Technol. Agric.*   (2019) 6:20

Page 10 of 11

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Page 11 of 11

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