ORIGINAL ARTICLE

Spatial Variation and Influencing Factors of Optical Characteristic of Water Extractable Organic Matter in Soils of Urban Grassland Across Climatic Zones in China

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Abstract

Dissolved organic matter (DOM) is the most active organic component in terrestrial ecosystems. In this study, 165 soil samples which were dominated by moss were collected from grasslands with similar vegetation in urban residential areas from 55 cities across different climatic zones of China. The water extractable organic matter (WEOM) of samples was analyzed. The results showed that WEOM content ranged from 23.5 to 517.6 mg kg^{-1} in the soil samples. Four fluorescent components including two tryptophan-like components (C1 and C4) and two humic-like components (C2 and C3) were identified by excitation–emission matrices combined with parallel factor analysis (EEM-PARAFAC). Proportions of humic-like components (C2+C3) were 54–66%, which is 1.2–2.0 times of the tryptophan-like component proportion (C1+C4) for all samples. The proportions of C2 and C3 were highest in the tropical monsoon climate (TroM) zone compared to that in the other climatic zones. Structural equation model and decomposition of variation showed that soil nutrient content was the main contributing factor of soil WEOM. Content Total nitrogen content and mean annual temperature (MAT) were the main factors influencing soil HIX but they had the opposite effects. Our results suggested that increasing soil nutrient content contributed the increase in soil WEOM content, but increasing MAT reduced the humification degree of WEOM.

Keywords Dissolved organic matter · EEM-PARAFAC · Temperature · Precipitation · Humification index

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1 Introduction

Dissolved organic matter (DOM) is typically the largest pool of detrital organic carbon in freshwater and marine ecosystems, which is the most important intermediate within the global carbon cycle (Jaffé et al. 2008). It is also the most active organic component in terrestrial ecosystems, which affects the microbial activity and the bioavailability of nutrients and heavy metals in the soil (Guo and Chorover 2003; Kalbitz et al. 2000; Kaiser and Kalbitz 2012). This effect is dependent not only on the DOM content, but also on the DOM composition. For example, amino acids are available to soil microorganisms and thus are easily converted into a source of nitrogen that plants can use directly (Zhou et al. 2021). In contrast, humic acids with large molecules are difficult to break down, but these compounds can complex heavy metals to reduce toxicity to plants (Spark et al. 1997). Therefore, revealing the influence of environmental factors on DOM content and composition is essential for understanding of soil microbial and geochemical processes.

Direct inputs of plant litter and dissolved organic compounds secreted by plant roots are the main sources of DOM in soil (Kiikkilä et al. 2013; van Stan and Stubbins 2018). The decomposition by soil microorganisms is the main process of DOM consumption in soil (O'Donnell et al. 2016). These two processes maintain a dynamic balance that determines the content and composition of soil DOM. On the one hand, higher temperature and precipitation are conducive to the growth of plants, which in turn produce more organic matter (including DOM) to be released into the soil (Wu et al. 2011a, b). On the other hand, higher temperature and soil moisture can also promote microbial metabolism and thus accelerate DOM consumption in the soil (O'Donnell et al. 2016). Therefore, how temperature and precipitation influence the content and composition of DOM is still an open question.

Several researchers indicated that climatic factors are major factors influencing soil DOM content and composition (Chantigny 2003; Rinot et al. 2021; Zhang et al. 2019a, b). However, this question is crucial in the context of global climate change at this stage, as the conclusions directly impact the decisions of soil environmental managers and agricultural producers in dealing with climate change. The best way to solve the problem is to carry out large-scale soil surveys, such as those on a continental scale. Gao et al. (2017) and Li et al. (2018) analyzed DOM composition of 19 farmland soil samples and 16 paddy soil samples across China, respectively. Qin et al. (2020) investigated DOM composition of four typical soil types under three different land-use regimes across China. However, they did not analyze the relationship between soil DOM composition and climatic factors.

Recently, Ding et al. (2020) analyzed 33 soil samples across China and indicated that aridity was the major factor influencing the chemical composition of soil DOM. However, the interference of land use was not eliminated in their studies, and this interference did have a profound influence on soil DOM content and composition (Li et al. 2019; Praise et al. 2020; Zhang et al. 2019a). Therefore, it is still necessary to carry out large-scale investigations eliminating land-use interference to accurately evaluate the influence of climatic factors on soil DOM.

Even if the same land use was selected, different dominant vegetation patterns would be formed due to changes in the climate. As far as forest is concerned, plants in the tropics and temperate zones are remarkably different. When farmland is concerned, rice is grown in most of the southern part of the world and crops like wheat are grown in the northern part. The farming systems for the two crop types are completely different. In order to solve this problem, urban green spaces such as grassland can be used to evaluate the influence

of climatic factors on soil DOM. Although grass species vary slightly in different climatic zones, this variation is limited.

The water extractable organic matter (WEOM) was used to represent soil DOM in this study. The aim of this study was to reveal the influence of temperature and precipitation on soil WEOM through a large-scale investigation. Soil samples which were dominated with moss in urban grassland was selected as the model ecosystem to eliminate land-use interference. The excitation emission matrix spectroscopy combined with parallel factor analysis (EEM-PARAFAC) was used to analyze soil WEOM composition. The study's results could be useful for decision-making in soil environmental management and agricultural production in the context of global climate change.

2 Materials and Methods

2.1 Soil Sampling

Soil samples, which were dominated with moss were collected in August 2019 from grasslands in urban residential areas across 55 cities in China (Fig. 1). The distribution of sampling sites was arranged as uniform as possible, although the overall pattern was dense in the southeast and sparse in the northwest due to the spatial distribution of cities and populations. The sampling sites covered a wide range of climatic conditions, with the
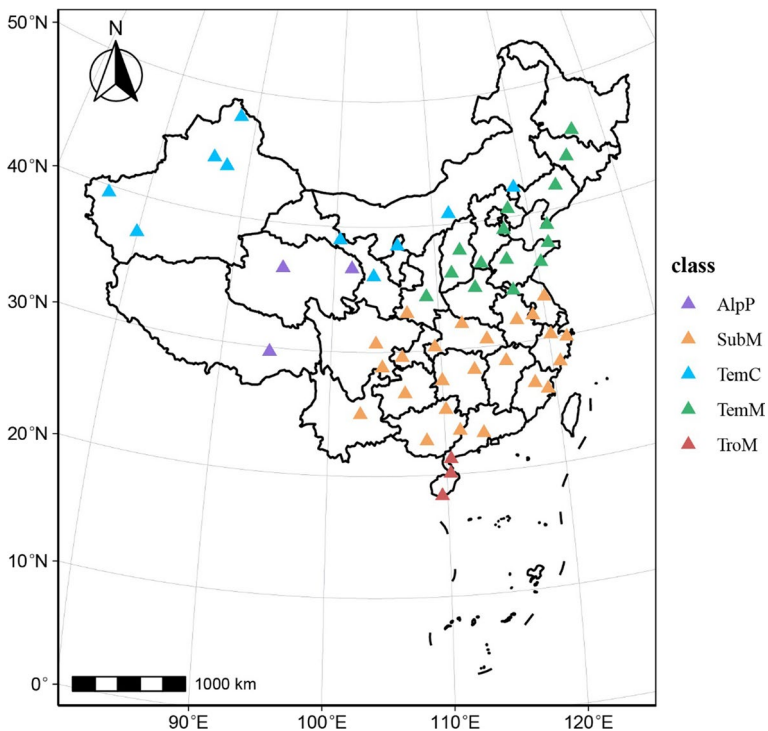
Fig. 1 Spatial distribution of 55 sampling sites across different climatic zones of China

mean annual temperature (MAT) of 1.0–24.8 °C and mean annual precipitation (MAP) of 44–2129 mm. To analyze the response of soil WEOM to temperature and precipitation, all data were grouped by the climatic factors. The data were divided into five groups according to mean annual temperature: < 7, 7–12, 12–15, 15–20, and > 20 °C. The data were divided into six groups according to mean annual precipitation: < 200, 200–400, 400–600, 600–800, 800–1200, and > 1200 mm. The sites belong to five climatic zones, namely, tropical monsoon climate (TroM), subtropical monsoon climate (SubM), temperate monsoon climate (TemP), temperate continental climate (TemC), and alpine plateau climate (AplP) zones as Fig. 1.

The operating strategy of all the urban grasslands was basically similar, because most of the residential complexes were managed by the same developer and property company. The most dominant grass family was Gramineae, with *Poa pratensis* L. and *Festuca elata* Keng ex E. Alexeev being the most dominant species. At each site, three random samples spaced 5 m apart from each other were collected from the 0 − 20 cm depth. A total of 165 soil samples were collected, air-dried, and milled to pass through a 150-mesh sieve.

2.2 Soil WEOM Extraction

The dry soil sample (3 g each) was weighed accurately into a 50-mL cleaned centrifuge tube. The tube was filled with 30 mL of deionized water and then shaken in a thermostatic water bath oscillator at 60 °C with 300 rpm for 30 min. Afterward, the tube was centrifuged at $10,000 \times g$ for 6 min and the supernatant was filtered through a 0.45-μm pore-sized filter membrane. The filtrate was used for subsequent chemical and spectral analyses. Previous researchers found that some centrifuge tubes and membrane filters could release DOM when using, which may influence the accuracy of the target sample DOM. For this, we did a preliminary test, and found a very limited increase in DOC content (< 0.45 mg/L) caused by their use. Considering its limited proportion in total DOC content, we ignored this effect in this study.

2.3 Soil Chemical Analysis

WEOM concentration was measured using a total organic carbon analyzer (TOC-L CPN; Shimadzu, Kyoto, Japan). Soil pH (1: 2.5 soil-to-water ratio), total nitrogen (TN), and total phosphorus (TP) were determined according to the methods described by Bao (2000).

2.4 Fluorescence and UV Spectroscopic Analysis

The three-dimensional fluorescence spectrum of WEOM was measured using a fluoresce spectrometer (RF-6000; Shimadzu). The excitation wavelength was 200–500 nm with an increment of 5 nm and the emission wavelength ranged from 250 to 550 nm with an increment of 2 nm. Prior to the analysis for EEMs, the samples were diluted with Milli-Q water to WEOM content < 10 mg/L (about 8 mg/L) to ensure that the maximum fluorescence signal was below the upper detection limit of the spectrometer (Wu et al. 2011a, b; Huang

et al. 2022). Internal filter effects of all EEMs were corrected using absorbance measurements, with most of the effects concerned with Raman scatter eliminated by subtracting the Milli-Q blank. The UV spectrum was analyzed over the range of 200–400 nm with a step of 1 nm using an UV–vis spectrometer (UV-1780; Shimadzu) without the dilution of samples.

2.5 Data Analysis

Meteorological data for the last ten years obtained from a network database (http://data.cma.cn/) were used for calculating the mean annual temperature and precipitation of each site. Three-dimensional fluorescence spectral data were analyzed by the PARAFAC method using MATLAB R2021b (Mathworks, Natick, MA, USA) combined with the DOMFluor toolbox (Stedmon and Bro 2008). Residuals, spectral loadings, Tucker congruence coefficients and split-half analysis were used to identify the number of components. The results of the PARAFAC model obtained in this study were queried in the OpenFluor database in order to search for quantitative matches with previously published and validated PARAFAC models (Murphy et al. 2014). The maximum fluorescence intensities (F_{max}) of the identified components were used to estimate their relative abundance (%). Fluorescence intensity was reported as arbitrary units (A.U.) that calculated by sample's fluorescence subtracting the Milli-Q blank. Four spectral indices, humus index (HIX), fluorescence index (FI), specific UV absorbance ($SUVA_{254}$), and spectral slope ratio (S_R) were calculated. Specifically, HIX was calculated as the peak integrated area under the emission spectra 435–480 nm divided by the emission spectra 300–445 nm at an excitation of 254 nm (Zsolnay et al. 1999). FI was calculated as the emission intensity at 470 nm divided by that at 520 nm at an excitation of 370 nm (Cory and McKnight 2005). The UV absorbance measurements made in naperian units, and the $SUVA_{254}$ (unit: L/mg-m) was calculated by Eq. (1) as the UV absorbance at 254 nm (at 1 cm of the quartz cell path length) divided by WEOM content (Abd Manan et al. 2020). S_R was calculated as the ratio of 275–295 nm spectral slope to 350–400 nm spectral slope (Helms et al. 2008).

$$SUVA_{254}(L/mg - m) = UVA_{254}(cm^{-1})/WEOM \text{ content } (mg/L) \times 100 \text{ cm/m} \quad (1)$$

Pearson correlation between the relative content and chemical properties of each WEOM component and environmental factors were calculated by OriginPro (2022b). Structural Equation Modeling (SEM) is multivariate statistical framework to build, estimate and test causal relationship models. It can clearly analyze the relationships between individual variables. The path coefficient (α) is an important index in SEM for assessing the direction and strength of relationship between variables. $\alpha > 0$ means positive relationship exists between the variables; $\alpha < 0$ means negative relationship exists. Higher |α| means stronger relationship between the variables. In this study, we used the "rfPermute" package of R software to identify the key environmental factors that explain WEOM variation. The "lavaan" package in R (version 3.4.2) and maximum likelihood estimation method were used to fit the structural equation model (SEM), and the response relationship between WEOM components and multiple environmental factors was evaluated quantitatively.

3 Results

3.1 Soil Chemical Properties

Soil WEOM content ranged from 23.5 to 517.6 mg kg^{-1} across the different climatic zones (Fig. 2), with the highest mean value (196.3 mg kg^{-1}) in the SubM zone and the lowest mean value (127.5 mg kg^{-1}) in the TemC zone. The mean soil pH in the TroM and SubM zones (6.78 and 6.93) was distinctly lower than the mean values in the other zones (7.62). The mean TN content in the TroM and SubM zones (816 and 747 mg kg^{-1}) was much higher than the mean values in the other three zones (357 mg k^{-1}). The mean TP content in the TroM zone (570 mg kg^{-1}) was remarkably lower than the mean values in the other four zones (775 mg kg^{-1}).

3.2 EEM-PARAFAC Components of Soil WEOM

Four fluorescent components were identified using EEMs-PARAFAC (C1-C4, Fig. 3, Table 1), which were compared with those in the OpenFlour database (Murphy et al., 2014). C1 exhibited a peak at the excitation/emission wavelengths ($\lambda_{Ex/Em}$) of 255/362 nm. This tryptophan-like component was previously found dominant in the extract of macrophyte, indicating its origin from plants (Zhou et al. 2021). The peak of C2 appeared at $\lambda_{Ex/Em} = 260/474$ nm. This UV humic acid-like component was also
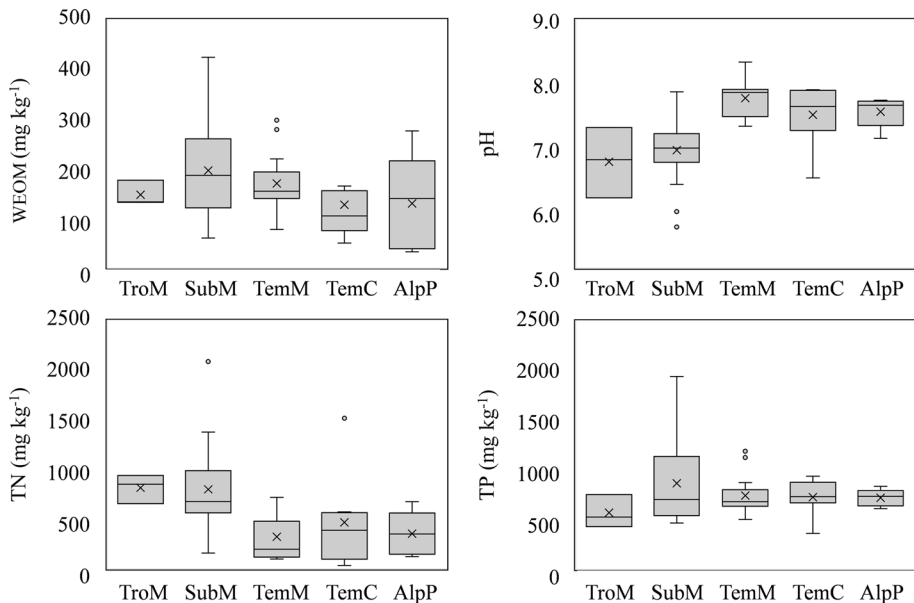
Fig. 2 Boxplots showing the chemical properties of soil samples from urban grasslands in five different climatic zones. Boxes indicate the upper and lower quartiles, the midline indicates the median, points indicate outliers, and whiskers indicate 1.5 times the interquartile range. WEOM, water extractable organic matter; TN, total nitrogen; TP, total phosphorus; TroM, tropical monsoon climate; SubM, subtropical monsoon climate; TemP, temperate monsoon climate; TemC, temperate continental climate; and AplP, alpine plateau climate. A similar notation is used hereafter
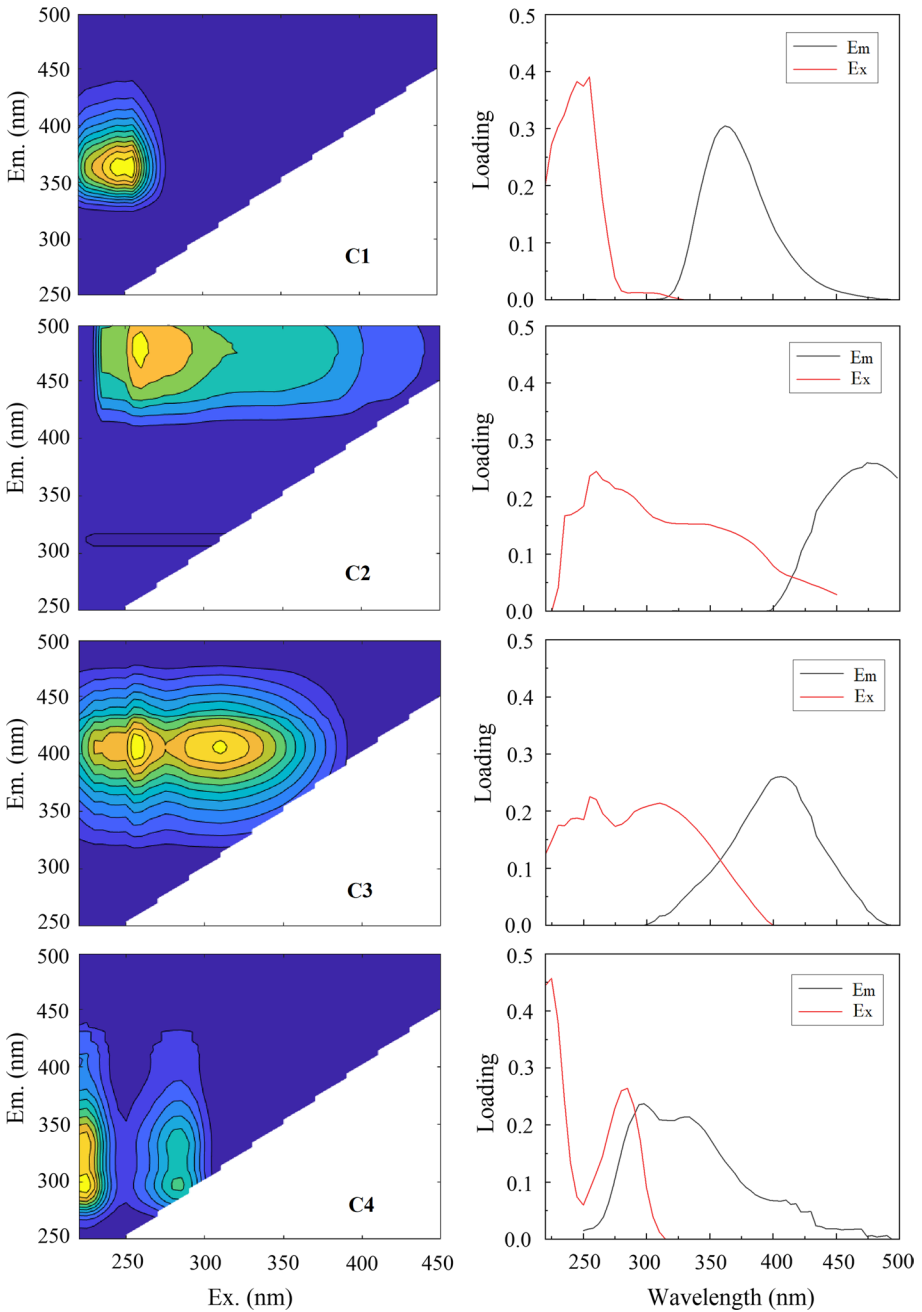
Fig. 3 EEM fluorescence spectra of WEOM components derived using PARAFAC modeling. The four-component model was validated by split-half validation

Table 1 Component features and their comparison with those in OpenFlour database

| Component	Ex. (nm)	Em. (nm)	Description	Tucker's congruence coefficient	References
C1	255	362	Tryptophan-like	0.99 (Ex)	C4 (Wang et al. 2020)
				0.94 (Em)	
C2	260	474	UV humic-like	0.99 (Ex)	C3 (Stedmon et al. 2003)
				0.99 (Em)	
			UV humic-like	0.98 (Ex)	C1(Yamashita et al. 2010)
				0.99 (Em)	
C3	255 (310)	406	Microbial humic-like	0.99 (Ex)	C2 (Chen et al. 2019)
				0.98 (Em)	
			Microbial humic-like	0.99 (Ex)	C3 (Kowalczuk et al. 2009)
				0.97 (Em)	
C4	225 (285)	298	Tryptophan-like	0.99 (Ex)	C6 (Gonçalves-Araujo et al. 2015)
				0.97 (Em)	

found in the EEM of soil and biochar extracts (Ge et al. 2021; Zhao et al. 2019), as well as in the aquatic environment (Stemon et al. 2003; Yamashita et al. 2010). C3 ($\lambda_{Ex/Em} = 255(310)/406$ nm) was considered as a microbial humic-like component with high molecular weight, which was widespread in wetlands and forested environments (Fellman et al. 2010; Chen et al. 2019). C4 ($\lambda_{Ex/Em} = 225(285)/298$ nm) was identified as a tryptophan-like component, which was previously described as amino acids, intact proteins, or less degraded peptide (Fellman et al. 2010; Gonçalves-Araujo et al. 2015). This component was widely found in the extracellular polymeric substances of cyanobacteria (Bai et al. 2017), so it could be considered as bacterial secretion.

The proportions of C2 (UV humic-like component) and C3 (microbial humic-like component) were highest in the TroM zone compared with in the other climatic zones (Fig. 4). The mean proportions of C1 and C4 (tryptophan-like component) were 2–6% and 32–41%, respectively, which had no large differences among the climatic zones. Overall, proportion of humic-like component (C2 + C3, mean value: 56%) is higher than that of tryptophan-like component (C1 + C4, mean value: 44%) when considering all sample sites in this study. Specifically, the former proportion (C2 + C3) was 66%, 55%, 54%, 61% and 59%, respectively, in TroM, SubM, TemM, TemC, AlpP zones, which is 2.0, 1.2, 1.2, 1.5, and 1.4 times of the latter proportion (C1 + C4).

3.3 Values of Four Spectral Indices

Both the values of HIX and SUVA$_{254}$ were lowest in the subM (2.73 and 1.67) (Fig. 5). The values of FI and S$_R$ in the TroM were the lowest and the values in the other four regions were almost similar to each other (1.60 and 3.40). The mean values of FI in the five regions were close to 1.7.
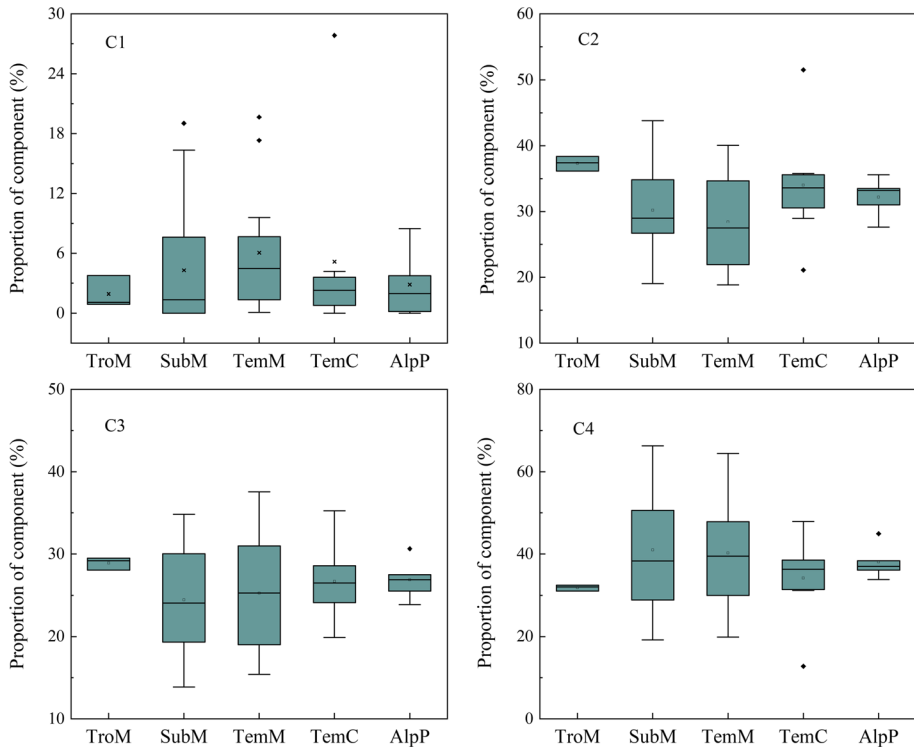
Fig. 4 Proportion of EEM-PARAFAC components of WEOM in soil samples from different climatic zones

3.4 Analysis of Influencing Factors

Pearson correlation showed that the contents of WEOM were positively correlated with TN and TP, while negatively correlated with FI (Fig. 6). Meanwhile, HIX was negatively correlated with MAT, FI was negatively correlated with MAP, and SUVA254 was negatively correlated with both MAT and MAP. SUVA254 was also positively correlated with pH. For WEOM components, C1 content was positively correlated with TP, while negatively with C2 and C3. C2 and C3 content showed a positive correlation, and C4 showed a negative correlation with C2 and C3.

The results of variation decomposition (Fig. 7) showed that the total explanation of climate and edaphic factors for WEOM was 29.9%, the explanation of edaphic factors for WEOM was 27%, and the joint explanation of edaphic factors and climate factors for WEOM was 1.76%. Climate and soil factors accounted for 27.1% of HIX, 14.7% of WEOMC, and 12.4% of WEOM. The coupling effect between them was weak.

The best-fit SEM quantified the relative contributions of the main environmental variables to WEOM and HIX. MAP, TN and TP had a strong influence on the accumulation of WEOM, while MAT played an important role in the degradation of WEOM (Fig. 7). The content of TN had a great contribution in the increase of HIX, and MAT, MAP and TP had the contribution in the decrease of HIX.
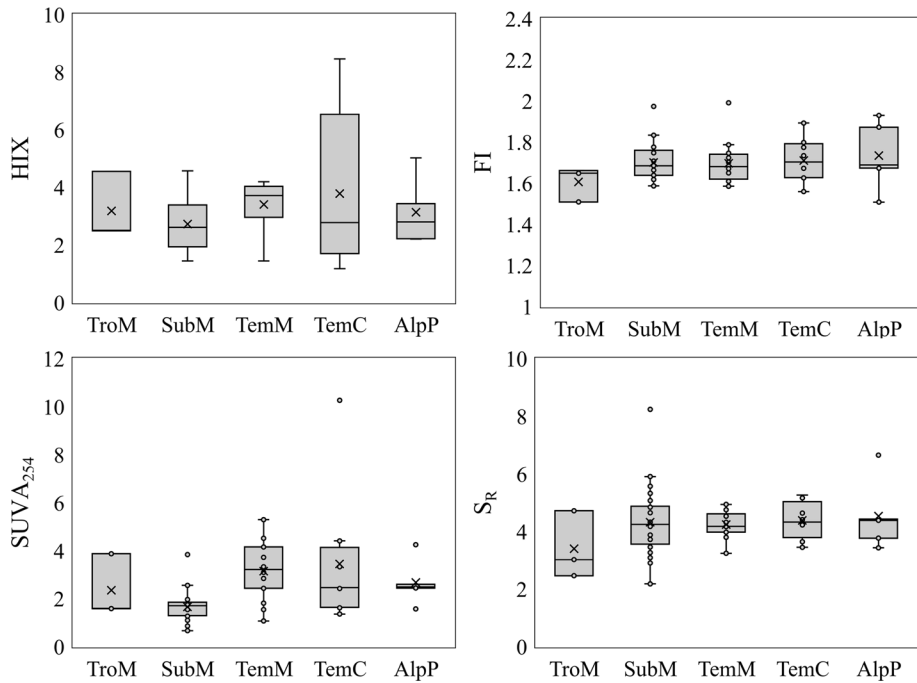
Fig. 5 Four spectral indices including humus index (HIX), fluorescence index (FI), specific UV absorbance (SUVA$_{254}$) and spectral slope ratio (S_R) of WEOM in soil samples from different climatic zones

4 Discussion

4.1 Driving Factors of Variation in Soil WEOM Content

DOM is continuously produced and consumed in soil, as soil being the core of terrestrial ecosystems and a key site for reginal carbon cycles. Any factors affecting soil carbon cycle may lead to changes of DOM characteristics. For instance, increase in exogenous organic carbon (i.e., plant biomass) could increase the DOM content (Bauhus et al. 1998; Eghdami et al. 2019), while microbial respiration and leaching may lead a decrease (Singh et al. 1999; Andrilli et al., 2019; Gmach et al. 2019). Soil nutrients can also affect DOM characteristics through affecting DOM production and consumption rate (Kaiser et al. 2001; Gmach et al. 2019; Shi et al. 2020). In this study, soil WEOM content ranged widely (23.5–517.6 mg kg^{-1}) over the wide zones (Fig. 2), and significantly positive correlation was found between soil WEOM content and soil TN and TP content (Fig. 6). Indeed, soil nutrient content was found to be the main contributing factor of soil WEOM content, followed by MAP according to SEM results (Fig. 7). Similar findings were reported by the previous studies. For instance, Liu et al. (2020) studied effects of N addition on soil stoichiometry in an alpine meadow and demonstrated that N addition predominantly controlled soil microbial stoichiometry through plant leaf and root stoichiometry, but not the composition of plant community and main microbial groups. This phenomenon also suggested that increasing plant leaf and root had an effect on soil carbon pool. Song et al. (2012) conducted 6 years'
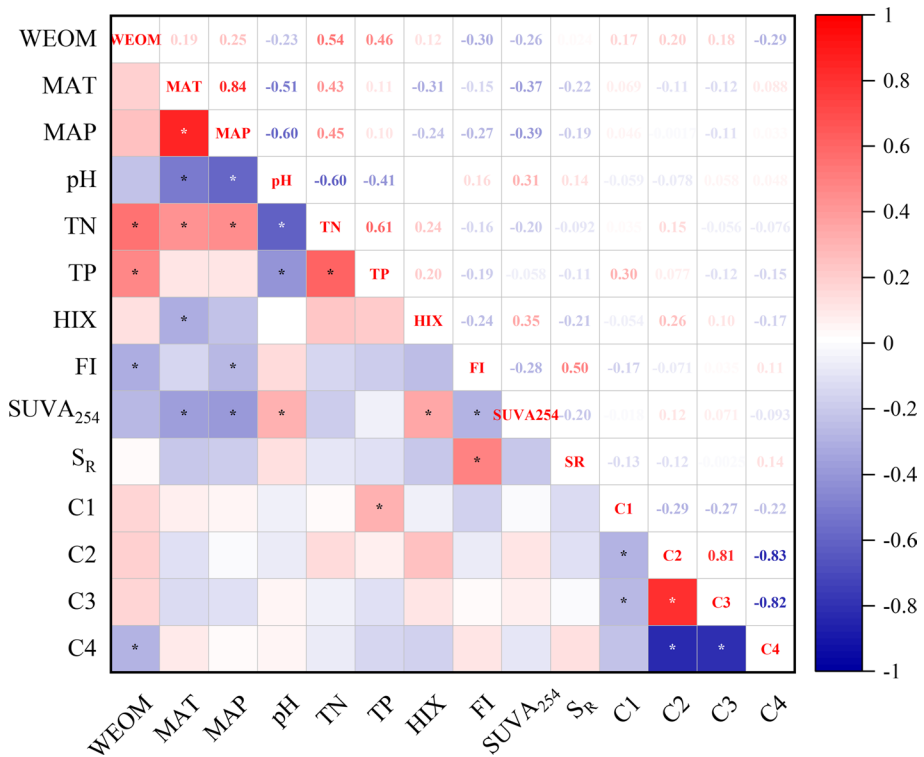
Fig. 6 Pearson correlations between environmental factors and WEOM features. "*" represents $p < 0.05$

treatments of experimental warming and increased precipitation in a temperate steppe in Northern China and found that increased precipitation transferred more soil organic carbon into the quick-decayed carbon pool. Cai et al. (2016) also found that watering increased DOC concentrations in a mixed grassland soil. All above results suggested that increasing soil nutrient content and MAP may promote plant growth (Cai et al. 2016; Luo et al. 2019) thereby improve the input of exogenous organic matter. Although the increase in the above factors promoted the decomposition efficiency of microorganisms, the consumption of DOC was far less than the amount of imported carbon source brought by these factors for plant growth promotion.

However, the results of SEM also showed that the relationship between MAT and soil WEOM content was not significant (Fig. 7). Nevertheless, MAT was always significantly positively related to MAP, which was significantly positively related to soil WEOM content. The increase in both temperature and precipitation promoted plant growth but also promoted microbial decomposition. The difference was that when the precipitation rose, the leaching also increased. The average soil WEOM content in the TroM was slightly lower than that in SubM also implied that in more humid TroM zone, stronger leaching would result in lower WEOM than SubM zone.
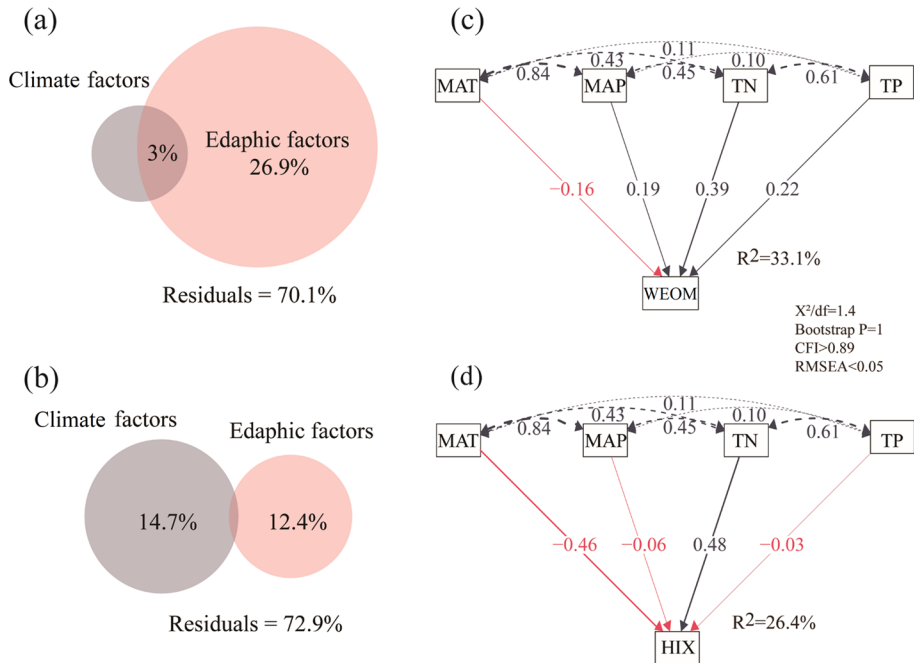
Fig. 7 Associations between soil WEOM features and the environmental factors. **a** Variation partitioning for potential drivers of soil WEOM content with climate factors and edaphic factors. The percentages represent the variance explained (Values <0 not shown). **b** Variation partitioning for potential drivers of HIX with climate factors and edaphic factors. The percentages represent the variance explained (Values <0 not shown). Cascading relationships of soil WEOM components with environmental factors. Best-supported structural equation models showed major pathways of the influences of environmental factors on **c** WEOM content, **d** HIX. Numbers on the black (i.e., positive relationships) and red (i.e., negative relationships) arrows indicate standardized path coefficients, while dotted arrows indicate pathways of the environmental factors. X^2/df, Chi square ratio degree of freedom; Bootstrap P, Bollen-Stine Bootstrap P value; CFI, comparativefit index; RESEA, root-mean-square error of approximation. R^2 indicates the variance of soil WEOM composition explained by the model

4.2 Driving Factors of Variation in WEOM Composition

Our results showed that there was little difference in the contributing rate of edaphic factors and climatic factors to HIX of soil WEOM (Fig. 7). Nevertheless, the results of SEM illustrated that the influence of TP and MAP on HIX was slight. TN content and MAT were the main factors influencing soil HIX but they had the opposite effects.

Li et al. (2022) studied the degradability of the standard and representative WEOM and found that HIX increased in the process of microbial degradation. In addition, they also demonstrated that humic acid had a higher HIX value than proteins and amino acids as well as the secretions of cyanobacteria and eukaryotes. This indicated that the HIX value of WEOM produced by organisms including microorganisms and eukaryotes was relatively low, and the HIX value would increase after the decomposition of these WEOM by microorganisms. In the current study, MAT negatively contributed to HIX but TN content had a positive contribution (Fig. 7). That was to say, MAT mainly promoted the decomposition of microorganisms while TN increased the input of fresh organic matter.

With regard to the spectral indices, there was a significant positive correlation between HIX and $SUVA_{254}$, which is similar to the finding of He et al. (2021). This phenomenon indicates that with an increasing degree of humification, the structure of WEOM becomes more complex and would be more difficult to be degraded. In addition, there was a significant positive correlation between FI and S_R in the current study (Fig. 6). However, neither Zhu et al. (2017) nor Gao et al. (2017) found similar patterns. A higher FI value indicates an increase in the amount of endogenous WEOM, while a higher S_R value indicates a decrease in the molecular weight of WEOM. It is generally believed that the endogenous WEOM is mainly protein-like compounds with small molecular weight. Therefore, in principle, the positive correlation between FI and S_R reveals that the molecular weight of WEOM decreases with an increasing proportion of endogenous WEOM.

The proportions of humic-like component (C2+C3) were highest in the TroM zones among five climate zones in this study (Fig. 4). The lower proportion of humic acid-like components in other climate zones indicated that the fresh fractions of amino acids and protein-like components gradually increased, while the decomposition products of terrestrial plant litter decreased in warmer soils (Fellman et al. 2010; Helms et al. 2008). The fresh fractions of amino acids and proteins-like components came from soil microbial secretion on the one hand, and from terrestrial plant secretion on the other hand. The humic acids were mainly resulting from the litter of terrestrial plants decomposed by microorganisms. It was generally believed that with the increase of temperature, the net productivity of terrestrial plants is increased (Fu et al. 2018; Wu et al. 2011a, b), and the activity and decomposition ability of soil microorganisms are enhanced (Barreiro et al. 2020; Compant et al. 2010). The result indicated that small organic molecules produced by plants and microorganisms, including cyanobacteria in soil crusts, could increase faster than the humic acids formed from plant litter by microbial decomposition.

A higher $SUVA_{254}$ indicates a greater aromaticity of DOM in soil (Fellman et al. 2010). The results of this study showed that with increasing temperature and precipitation, the aromaticity degree of soil WEOM gradually decreased (Fig. 7). This trend indicated that under higher temperature and precipitation conditions, the chemical activity of soil WEOM is gradually increased, which may be easier to be used by microorganisms.

The results of this study clearly showed that climatic factors directly influenced the composition of soil WEOM (Fig. 7). Similarly, Ding et al. (2020) found that aridity directly affected the composition of soil WEOM. However, Gao et al. (2017) analyzed the WEOM composition of 18 farmland soil samples across China, finding no large differences among different climatic regions, and this was partly due to the small number of samples. Moreover, the influence of manure application and other tillage measures on WEOM composition could not be excluded. Li et al. (2018) analyzed 16 paddy soil samples across China and found that soil pH was an essential factor influencing soil WEOM composition. However, there was no significant correlation between soil pH and WEOM components in the current study (Fig. 6). Yet, a significant positive correlation between soil pH and $SUVA_{254}$ was found (Fig. 6) indicating that soil pH may affect the fluorescence properties of WEOM to a certain extent.

Some studies showed that land use and even the species of trees and grasses had an impact on WEOM composition (Howard et al. 2018; Seifert et al. 2016; Stubbins et al. 2017; Zhang et al. 2019a, b). The results of this study excluded the influence of these factors to a large extent by selecting urban grassland with similar vegetation. Although the influence of soil chemical factors cannot be ruled out in this study, this influence might be limited based on the trend of WEOM along the climatic gradient.

5 Conclusions

This work studied soil WEOM and nutrient content characteristics in urban grassland across climatic zones in China. The main influencing factors of soil WEOM were analyzed systematically. Results showed that the highest soil WEOM content (196.3 mg kg^{-1}) existed in the SubM zone and the lowest (127.5 mg kg^{-1}) existed in the TemC zone. The soil TN content in the TroM and SubM zones (816 and 747 mg kg^{-1}) was much higher than the values in the other three zones (357 mg k^{-1}). The TP content in the TroM zone (570 mg kg^{-1}) was lower than that in the other four zones (775 mg kg^{-1}). SEM showed that soil nutrient content was the main contributing factor of soil WEOM content. In addition, the influence of TP and MAP on humification index (HIX) was slight. In addition, the content of TN had a great contribution in the increase in HIX, and MAT, MAP and TP had the contribution in the decrease in HIX. Our results suggested that increasing soil nutrient content contributed the increase in soil WEOM content, but increasing MAT reduced the humification degree of WEOM.

Author Contributions BP: Visualization, Writing—original draft, Writing—review and editing. SL: Conceptualization, Investigation. YD: Investigation. ML: Conceptualization, Methodology, Writing—review and editing, Supervision, Funding acquisition.

Data Availability The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Conflict of interest The authors declare they have no conflict of interest.

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