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The Influence of Green Manure Planting on the Spectroscopic Characteristics of Dissolved Organic Matter in Freshwater-Leached Saline–Alkali Soil at Different Depths

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Abstract: This study investigated the influence of green manure planting on the spectroscopic properties of dissolved organic matter (DOM) in saline–alkali soil under freshwater leaching conditions at different soil depths. The UV_{254}, UV_{253}/UV_{203}, α_{300}, α_{355}, $SUVA_{254}$, $SUVA_{260}$, and S_R ultraviolet parameters indicated reductions in the content of large molecular substances, benzene ring substitution degree, colored dissolved organic matter, aromaticity, and hydrophobic components in the soil leachate DOM with an increasing soil depth. Compared with the non-green manure treatment control, green manure planting mitigated the leaching of dissolved organic matter in soil during saline irrigation, with rape green manure demonstrating superior effectiveness. Utilizing three-dimensional fluorescence combined with parallel factor analysis, this study analyzed three fluorescent components of soil leachate DOM: C1 (visible-light fulvic acid), C2 (humic acid), and C3 (tyrosine-like protein). The combined contribution of the two humic substance components (C1 + C2) was approximately 70%, indicating the dominance of humic substances in leachate DOM. The fluorescence parameters of soil leachate DOM included an average of the fluorescence index (FI) values between 1.4 and 1.9, low humification index (HIX) values consistently below 4, and biological index (BIX) values ranging from 0.8 to 1.0, suggesting a mixed source, low humification degree, poor stability, and moderate self-source characteristics. Compared with the non-green manure treatment control, both the green manure treatments exhibited a relatively higher proportion of biogenic sources and humification degree in soil leachate DOM. This suggests that planting green manure can reduce the relative DOM content under freshwater leaching conditions, increase the proportion of biogenic sources in soil leachate DOM, and enhance soil humification. Planting rapeseed green manure can diminish the leaching of DOM from land sources and augment soil humification.

Keywords: saline–alkali soil; green manure; freshwater leaching; soil-dissolved organic matter; spectroscopic characteristics

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1. Introduction

The saline–alkali land area in Shandong Province covers 5926.73 km^2, mainly concentrated in the Yellow River Delta region [1]. Salt accumulates in the soil surface layer due to upward salt flow and evaporation from the soil and groundwater, causing gradual soil salinization [2,3]. Dissolved organic matter (DOM) in soil generally denotes water-soluble organic matter capable of passing through a 0.45 μm filter membrane. It comprises a continuum or mixture of structurally diverse and variably sized organic compounds [4,5]. Freshwater leaching is a crucial method for ameliorating saline–alkali soil in hydraulic engineering measures, and is regarded as one of the simplest and most effective techniques among various improvement measures [6]. The leaching process during freshwater salinization profoundly influences the leaching effect of DOM in soil, potentially disrupting the balance of the soil microecosystem. Despite constituting a small fraction of soil organic matter, DOM represents the most active carbon pool in soil organic carbon, playing a pivotal role in global carbon cycling and climate change [7]. It influences the microbial quantity and activity in the soil, constituting a necessary element for plant growth [8,9].

DOM can be classified into endogenous and exogenous types according to its origin. Various theories regarding the sources of soil DOM exist. Some studies propose that plant litter decomposition is the primary source of soil DOM [10]. The leaching of soil organic matter and microbial decomposition are considered the major sources [11]. Some scholars have proposed that plant root exudates are also essential sources of soil DOM [12]. In recent years, human activities, including agricultural fertilization, irrigation, industrial waste, and domestic sewage, have been recognized as additional sources of soil DOM [13,14]. Due to the diverse functional groups in DOM components, their absorption characteristics vary across different wavelengths. Thus, spectroscopic characteristics are valuable tools for DOM characterization [15]. Researchers worldwide commonly employ ultraviolet–visible absorption spectroscopy (UV–Vis) and three-dimensional fluorescence spectroscopy (excitation emission matrix spectra—EEMs) as spectral analysis methods, often combined with parallel factor analysis (PARAFAC) and fluorescence intensity indices. This integrated approach offers a convenient, rapid, and precise means of obtaining the fluorescence components and proportions of DOM.

Ultraviolet–visible spectroscopy revealed that the SUVA_{254} (aromaticity), SUVA_{260} (hydrophobic components), and S_{R} values (DOM molecular weight) of cultivated land DOM were higher than those of forest soil DOM. Additionally, higher values were observed in autumn than in spring in cultivated land [4]. A study on the seasonal variation in the overlying water DOM in reservoir sediment revealed $\mathrm{E}_3/\mathrm{E}_4$ values greater than 3.5 and S_{R} values exceeding 1. These values indicate that DOM is predominantly fulvic acid-based and primarily originates from biogenic sources [16]. Moreover, the fulvic acid content in the leachate DOM from both irrigation sources was higher than that of humic acid [17]. A study on the seasonal dynamics of soil DOM revealed that the average humification index (HIX) value of autumn soil DOM was higher than that of spring soil, suggesting a relatively higher humification degree in autumn soil DOM [18]. Cultivated land soil in autumn contains more protein-like substances than in spring [4]. Relevant studies indicated significant correlations between different fluorescence parameters. Specifically, the fluorescence index (FI) and biological index (BIX) showed a significant positive correlation, while HIX and BIX exhibited a negative correlation. These findings suggested that different fluorescence parameters played crucial indicative roles in characterizing DOM's source and humification degree [19].

Planting green manure not only makes full use of land and light-heat resources [20], prevents soil wind erosion, reduces evaporation [2], decreases soil salinity, improves soil structure and quality [21], and increases soil nutrients [22], but also sequesters carbon and fixes nitrogen, reduces nitrogen loss during irrigation, and enhances nitrogen supply capacity [23,24]. Moreover, since DOM represents the most active carbon pool in soil organic carbon, studying the impact of green manure on DOM is of great significance for traditional agriculture and the development and utilization of saline–alkali land. To date, minimal research on the impact of green manure on soil DOM has been reported. Given the potential production or consumption of soil DOM during the growth period of green manure planting, and the inevitable changes in soil DOM during leaching processes, it is imperative to study these changes in characteristics. In this study, UV–visible absorption spectroscopy and three-dimensional fluorescence spectroscopy were employed to analyze the DOM in different leachate solutions after winter fallow and green manure planting under saline irrigation. The objective was to understand the influence of green manure planting on the spectroscopic characteristics of soil leachate DOM after saline irrigation. This research aimed to provide a theoretical basis for sustainable agricultural development in saline–alkali land areas under saline irrigation.

2. Materials and Methods

2.1. Study Site

The experimental site was located in the Agricultural High-Tech Industry Demonstration Zone of the Yellow River Delta in Dongying City, Shandong Province (37°18′40″ N, 118°39′18″ E). This region experiences a temperate climate with a continental monsoon season, characterized by an average annual temperature of 12.3 °C and an average precipitation of 587.4 mm. Precipitation is concentrated in July and August. The tested soil was coastal saline–alkali soil, and its basic soil physicochemical properties are shown in Table 1.

Table 1. Basic physical and chemical properties of test soil.

Soil Depth	Soil pH	Total Salt Quantity/(g/kg)	Organic Matter/(g/kg)	Total Nitrogen/(g/kg)	Available Phosphorus/(mg/kg)	Available Potassium/(mg/kg)
0~30	8.38 ± 0.02	1.46 ± 0.03	11.78 ± 0.45	0.82 ± 0.13	7.26 ± 0.75	284.27 ± 8.60
30~60	8.59 ± 0.03	1.77 ± 0.05	4.63 ± 0.15	0.56 ± 0.06	4.59 ± 0.16	201.85 ± 6.01
60~90	8.78 ± 0.03	2.22 ± 0.02	2.70 ± 0.08	0.39 ± 0.01	2.43 ± 0.16	185.39 ± 6.34

2.2. Experimental Design

The experiment was conducted from October 2021 to May 2022, with three treatments: non-green manure treatment (T1), Dongmu70 rye treatment (T2), and rape treatment (T3). Each treatment had three replications, resulting in nine experimental plots. The experimental plots followed a completely randomized block arrangement. Each experimental plot had an area of 5 m × 8 m, and plots were separated using a double-layer salt membrane with a depth of 100 cm. Green manure was sown on 25 October 2021, with seeding rates of 180 $kg \cdot ha^{-1}$ for Dongmu70 rye and 24 $kg \cdot ha^{-1}$ for rape, both with a row spacing of 20 cm. During the green manure regreening period, three negative-pressure ceramic-soil-solution in situ collectors were installed in each plot at depths of 30 cm, 60 cm, and 90 cm, with a horizontal spacing of 50 cm between the collectors. Freshwater leaching was conducted on 29 April, with an irrigation amount of 2000 $t \cdot ha^{-1}$.

2.3. Ultraviolet–Visible Absorption Spectroscopy and Three-Dimensional Fluorescence Spectroscopy Measurement of Soil Leachate DOM

The collected soil leachates were filtered through a 0.45 μm glass fiber filter membrane to obtain DOM extracts, which served as the DOM extraction solutions. Two thirds of each DOM extraction solution was poured into 10 mm quartz cuvettes using ultrapure water as a blank. Ultraviolet–visible absorption spectroscopy (Agilent 8453, Agilent Technologies, Santa Clara, CA, USA) was employed to scan the wavelength range of 200–800 nm. The scanning speed was set at 300 $nm \cdot min^{-1}$ with a wavelength interval of 1 nm, providing the ultraviolet–visible absorption spectra for each leachate's DOM.

The DOM extraction solution from soil leachate was added to a 10 mm quartz cuvette. A Hitachi F-7000 fluorescence spectrophotometer (Hitachi, Tokyo, Japan) was utilized to scan and obtain three-dimensional fluorescence spectra (3D-EEMs). The parameters were set as follows: the excitation wavelength (Ex) scanning range was 200–450 nm, and the emission wavelength (Em) scanning range was 250–550 nm, with intervals of 5 nm for both Ex and Em wavelength scans. The slit widths of the excitation and emission monochromators were both set at 5 nm, and the scanning speed was 1400 $nm \cdot min^{-1}$. Ultrapure water served as a blank, and the instrument automatically corrected the scanned fluorescence spectra.

2.4. Parameter Analysis

2.4.1. Ultraviolet–Visible Absorption Spectroscopy Characteristic Parameters

The selected ultraviolet spectral parameters included UV_{254}, UV_{253}/UV_{203}, α_{300}, α_{355}, $SUVA_{254}$, $SUVA_{260}$, and S_R [25].

UV_{254} represents the ultraviolet absorbance at a wavelength of 254 nm.

UV_{253}/UV_{203} is the ratio of ultraviolet absorbance at 253 nm and 203 nm wavelengths, indicating the degree of substitution on the benzene ring in the DOM.

α_{300} and α_{355} represent the ultraviolet absorption coefficients at 300 nm and 355 nm wavelengths, respectively. The calculation formula is

$$\alpha(\lambda) = 2.303 \times A(\lambda)/L \tag{1}$$

where $\alpha(\lambda)$ represents the ultraviolet absorption coefficient at the wavelength m^{-1}; $A(\lambda)$ is the absorbance at wavelength λ; and L is the optical path length (cuvette length) set at 0.01 m.

$SUVA_{254}$ and $SUVA_{260}$ refer to the ratios of the ultraviolet absorption coefficients at 254 nm and 260 nm wavelengths to the dissolved organic carbon (DOC) concentration. The calculation formula is

$$SUVA_{(\lambda)} = \alpha(\lambda)/c(DOC) \tag{2}$$

where c(DOC) represents the sample dissolved organic carbon (DOC) concentration in $mg \cdot L^{-1}$.

The S_R value is the ratio of the absorbance slopes $S_{275–295}$ nm and $S_{350–400}$ nm within the wavelength ranges of 275–295 and 350–400 nm, respectively. It can characterize the molecular size of the DOM and its potential sources and is inversely proportional to the molecular weight of the DOM. When $S_R < 1$, it indicates the exogenous characteristics of the DOM; when $S_R > 1$, it indicates the endogenous characteristics of the DOM. The absorbance slopes $S_{275–295}$ and $S_{350–400}$ are characterized using Formula (3), and the S_R is obtained using Formula (4).

$$\alpha(\lambda) = \alpha(\lambda_0)\exp[-S(\lambda_0 - \lambda)] \tag{3}$$

$$S_R = S_{275\text{-}295}/S_{350\text{-}400} \tag{4}$$

where λ_0 represents the reference wavelength in nm, typically set at 440 nm; S is the absorbance slope in nm^{-1}; and the fitting range is within 275–295 nm and 350–400 nm.

2.4.2. EEMs–PARAFAC

Parallel factor analysis (EEMs–PARAFAC) is a mathematical model based on the alternating least squares algorithm and trilinear decomposition theory [26]. It is employed to achieve the "mathematical separation" of fluorescence information, decomposing the fluorescence signals of DOM in excitation emission matrix spectra (EEMs) into several relatively independent fluorescence components. The DOMFluor toolbox in MATLAB 2018a software was utilized for preprocessing the imported raw fluorescence spectral data matrix groups (i.e., subtracting Raman scattering, filtering, and removing outliers). Subsequently, PARAFAC analysis was performed, and the residual analysis, split-half analysis, and split-half validation methods were employed to simulate the PARAFAC models with 2~7 components for the samples. This determined the optimal number of fluorescence components in the DOM in the leaching solutions and the corresponding component concentration score values (Fmax) for each sample. Thus, the PARAFAC model was established.

2.4.3. Three-Dimensional Fluorescence Analysis

The commonly used characterization indices for the three-dimensional fluorescence analysis of soil DOM include FI, HIX, and BIX [27,28].

2.4.4. Other Data Analyses

The original experimental data were processed and tabulated using Excel 2019. Statistical analysis, significance analysis, and correlation analysis were obtained through the factorial experiment and performed using SPSS 22.0 software to analyze. Origin 2018 was used for plotting and linear-fitting the UV–visible absorption spectra.

3. Results and Analysis

3.1. Changes in UV Parameters of DOM in Soil Leachate

3.1.1. UV_{254} and UV_{253}/UV_{203}

Table 2 shows the changes in the UV_{254} and UV_{253}/UV_{203} values of the soil leachate DOM after freshwater leaching with the different treatments. In Table 2, the average UV_{254} values of the leachate DOM for each treatment are 0.236 ± 0.040 cm^{-1}, 0.271 ± 0.025 cm^{-1}, and 0.171 ± 0.045 cm^{-1} at the 0–30 cm depth, respectively; 0.208 ± 0.033 cm^{-1}, 0.146 ± 0.044 cm^{-1}, and 0.168 ± 0.027 cm^{-1} at the 30–60 cm depth, respectively; and 0.093 ± 0.021 cm^{-1}, 0.117 ± 0.036 cm^{-1}, and 0.124 ± 0.034 cm^{-1} at the 60–90 cm depth, respectively. The average UV_{254} values of the leachate DOM for each treatment gradually decreased with the increasing soil layer depth. Compared with the T1 treatment, the T3 treatment significantly reduced the DOM content in the 0–60 cm soil layer leachate ($p < 0.05$).

Table 2. Changes in UV parameters' values of soil-leaching solution DOM.

Sampling Date	**Treatment**	**Depth (cm)**	**UV254 (cm^{-1})**	**UV253/UV203**	**α_{300} (m^{-1})**	**α_{355} (m^{-1})**	**$SUVA_{254}$ L·(mg·m)$^{-1}$**	**$SUVA_{260}$ L·(mg·m)$^{-1}$**	**S_R**
4.30	T1	0–30	0.186 ± 0.010	0.037 ± 0.003	29.94 ± 3.14	7.37 ± 0.90	4.73 ± 0.23	4.35 ± 0.20	0.80 ± 0.01
		30–60	0.178 ± 0.005	0.026 ± 0.001	21.99 ± 0.49	7.37 ± 0.48	4.86 ± 0.29	4.49 ± 0.28	0.49 ± 0.04
		60–90	0.126 ± 0.011	0.012 ± 0.004	14.39 ± 1.47	4.26 ± 0.49	4.28 ± 0.28	3.98 ± 0.10	0.85 ± 0.08
	T2	0–30	0.266 ± 0.022	0.073 ± 0.006	29.71 ± 2.61	10.36 ± 0.62	4.90 ± 0.43	4.61 ± 0.36	0.73 ± 0.04
		30–60	0.186 ± 0.040	0.033 ± 0.002	20.84 ± 1.40	6.91 ± 0.65	3.39 ± 0.30	3.20 ± 0.35	0.64 ± 0.03
		60–90	0.165 ± 0.018	0.006 ± 0.003	20.15 ± 1.07	7.02 ± 0.44	3.04 ± 0.04	3.75 ± 0.06	0.90 ± 0.01
	T3	0–30	0.111 ± 0.028	0.011 ± 0.003	13.13 ± 1.91	3.80 ± 0.13	3.75 ± 0.39	3.45 ± 0.16	0.79 ± 0.01
		30–60	0.155 ± 0.036	0.024 ± 0.001	16.35 ± 1.54	6.45 ± 0.60	2.14 ± 0.22	1.97 ± 0.22	0.51 ± 0.01
		60–90	0.104 ± 0.011	0.007 ± 0.002	12.32 ± 1.79	3.57 ± 0.49	2.20 ± 0.10	2.02 ± 0.08	0.86 ± 0.02
5.2	T1	0–30	0.217 ± 0.009	0.042 ± 0.003	31.09 ± 2.64	7.72 ± 0.44	3.79 ± 0.45	3.37 ± 0.27	0.82 ± 0.05
		30–60	0.211 ± 0.030	0.022 ± 0.003	31.21 ± 2.00	13.13 ± 0.98	4.22 ± 0.37	3.86 ± 0.46	0.45 ± 0.09
		60–90	0.087 ± 0.010	0.012 ± 0.004	12.67 ± 1.26	2.42 ± 0.18	2.81 ± 0.18	2.45 ± 0.10	0.96 ± 0.02
	T2	0–30	0.270 ± 0.005	0.116 ± 0.004	40.65 ± 2.77	16.93 ± 1.39	4.23 ± 0.34	3.84 ± 0.17	0.85 ± 0.04
		30–60	0.106 ± 0.014	0.015 ± 0.001	13.13 ± 0.91	4.15 ± 0.27	2.08 ± 0.19	1.91 ± 0.22	0.87 ± 0.03
		60–90	0.088 ± 0.010	0.006 ± 0.003	8.18 ± 0.44	1.96 ± 0.11	1.94 ± 0.22	1.73 ± 0.17	0.98 ± 0.05
	T3	0–30	0.140 ± 0.010	0.020 ± 0.003	16.24 ± 0.16	5.53 ± 0.01	2.50 ± 0.27	2.31 ± 0.36	0.95 ± 0.03
		30–60	0.121 ± 0.017	0.016 ± 0.002	15.66 ± 1.42	6.56 ± 0.69	2.29 ± 0.31	2.07 ± 0.14	0.62 ± 0.11
		60–90	0.070 ± 0.020	0.007 ± 0.002	9.56 ± 0.42	2.53 ± 0.13	1.94 ± 0.16	1.76 ± 0.15	0.96 ± 0.08
5.4	T1	0–30	0.268 ± 0.001	0.042 ± 0.002	32.36 ± 3.03	11.86 ± 1.14	2.95 ± 0.24	2.79 ± 0.18	0.97 ± 0.12
		30–60	0.178 ± 0.031	0.018 ± 0.003	24.76 ± 1.50	6.68 ± 0.33	3.22 ± 0.43	3.00 ± 0.28	0.75 ± 0.04
		60–90	0.089 ± 0.004	0.012 ± 0.001	12.78 ± 1.00	2.53 ± 0.17	2.24 ± 0.27	2.00 ± 0.18	1.10 ± 0.02
	T2	0–30	0.294 ± 0.018	0.108 ± 0.005	31.09 ± 1.77	10.71 ± 1.09	2.38 ± 0.13	2.15 ± 0.09	1.06 ± 0.03
		30–60	0.093 ± 0.016	0.013 ± 0.003	11.86 ± 1.09	3.45 ± 0.17	2.38 ± 0.26	2.29 ± 0.16	1.25 ± 0.12
		60–90	0.093 ± 0.009	0.010 ± 0.001	12.44 ± 0.65	3.11 ± 0.16	2.25 ± 0.06	2.03 ± 0.04	1.21 ± 0.02
	T3	0–30	0.153 ± 0.025	0.045 ± 0.003	17.73 ± 2.28	6.33 ± 0.81	3.54 ± 0.12	3.26 ± 0.11	1.07 ± 0.02
		30–60	0.172 ± 0.017	0.024 ± 0.008	22.63 ± 1.77	7.63 ± 0.37	2.99 ± 0.43	2.69 ± 0.23	0.92 ± 0.07
		60–90	0.141 ± 0.003	0.020 ± 0.005	18.08 ± 0.81	5.18 ± 0.49	1.52 ± 0.15	1.41 ± 0.04	1.13 ± 0.02
5.6	T1	0–30	0.295 ± 0.009	0.041 ± 0.007	35.70 ± 2.05	14.39 ± 1.35	3.46 ± 0.04	3.10 ± 0.15	0.94 ± 0.11
		30–60	0.199 ± 0.012	0.040 ± 0.002	27.06 ± 2.40	8.18 ± 0.64	2.88 ± 0.24	2.62 ± 0.12	0.69 ± 0.04
		60–90	0.093 ± 0.016	0.013 ± 0.003	13.36 ± 1.23	2.30 ± 0.33	2.85 ± 0.21	2.56 ± 0.21	1.02 ± 0.02
	T2	0–30	0.298 ± 0.016	0.052 ± 0.005	33.19 ± 1.58	7.25 ± 0.46	2.09 ± 0.02	1.89 ± 0.02	0.81 ± 0.04
		30–60	0.129 ± 0.016	0.013 ± 0.007	16.81 ± 1.77	5.53 ± 0.58	3.12 ± 0.24	2.84 ± 0.21	0.66 ± 0.11
		60–90	0.118 ± 0.012	0.012 ± 0.001	15.66 ± 0.58	4.15 ± 0.47	3.08 ± 0.29	2.81 ± 0.27	0.95 ± 0.11
	T3	0–30	0.195 ± 0.044	0.061 ± 0.003	24.41 ± 1.82	12.55 ± 0.72	2.84 ± 0.22	2.61 ± 0.24	0.85 ± 0.09
		30–60	0.189 ± 0.011	0.022 ± 0.002	23.45 ± 2.54	9.02 ± 0.67	3.03 ± 0.17	2.76 ± 0.21	0.57 ± 0.05
		60–90	0.118 ± 0.014	0.012 ± 0.004	16.70 ± 1.35	5.53 ± 0.25	2.53 ± 0.36	2.27 ± 0.25	0.87 ± 0.11
5.9	T1	0–30	0.243 ± 0.015	0.025 ± 0.001	29.48 ± 2.26	11.05 ± 0.49	2.81 ± 0.22	2.52 ± 0.15	0.62 ± 0.06
		30–60	0.217 ± 0.018	0.048 ± 0.006	30.75 ± 1.84	12.09 ± 0.76	2.88 ± 0.29	2.63 ± 0.34	0.80 ± 0.05
		60–90	0.063 ± 0.007	0.013 ± 0.002	9.56 ± 1.12	2.65 ± 0.19	2.45 ± 0.17	1.32 ± 0.13	1.05 ± 0.11
	T2	0–30	0.272 ± 0.027	0.028 ± 0.001	36.72 ± 3.73	9.44 ± 0.53	3.05 ± 0.35	2.75 ± 0.13	0.86 ± 0.01
		30–60	0.201 ± 0.030	0.029 ± 0.009	27.41 ± 2.93	6.91 ± 0.27	2.93 ± 0.35	2.67 ± 0.29	0.98 ± 0.03
		60–90	0.140 ± 0.009	0.020 ± 0.004	18.08 ± 1.35	5.07 ± 0.60	2.35 ± 0.05	1.70 ± 0.03	0.98 ± 0.04
	T3	0–30	0.236 ± 0.001	0.042 ± 0.006	29.48 ± 0.65	11.17 ± 0.81	2.33 ± 0.36	2.17 ± 0.19	0.58 ± 0.13
		30–60	0.191 ± 0.028	0.040 ± 0.004	24.95 ± 1.19	8.48 ± 0.64	2.42 ± 0.17	2.28 ± 0.23	0.85 ± 0.04
		60–90	0.167 ± 0.012	0.030 ± 0.003	19.00 ± 0.86	5.53 ± 0.55	2.39 ± 0.28	2.20 ± 0.19	1.04 ± 0.09

Table 2. *Cont.*

Sampling Date	Treatment	Depth (cm)	UV254 (cm^{-1})	UV253/UV203	α_{300} (m^{-1})	α_{355} (m^{-1})	$SUVA_{254}$ $L\cdot(mg\cdot m)^{-1}$	$SUVA_{260}$ $L\cdot(mg\cdot m)^{-1}$	S_R
5.12	T1	0–30	0.209 ± 0.018	0.038 ± 0.006	26.14 ± 1.65	7.95 ± 0.47	3.80 ± 0.31	3.41 ± 0.26	0.51 ± 0.03
		30–60	0.268 ± 0.010	0.038 ± 0.004	36.16 ± 2.26	12.44 ± 0.93	2.41 ± 0.14	2.14 ± 0.21	0.70 ± 0.07
		60–90	0.101 ± 0.008	0.014 ± 0.003	10.59 ± 0.21	2.76 ± 0.16	1.80 ± 0.14	1.62 ± 0.14	0.85 ± 0.02
	T2	0–30	0.227 ± 0.003	0.033 ± 0.003	32.47 ± 1.63	7.02 ± 0.81	2.84 ± 0.11	2.52 ± 0.07	0.69 ± 0.02
		30–60	0.161 ± 0.015	0.017 ± 0.005	23.38 ± 2.44	5.18 ± 0.76	2.80 ± 0.19	2.48 ± 0.19	0.73 ± 0.06
		60–90	0.123 ± 0.017	0.013 ± 0.007	15.43 ± 0.44	3.80 ± 0.11	1.85 ± 0.12	1.23 ± 0.11	0.70 ± 0.07
	T3	0–30	0.189 ± 0.018	0.030 ± 0.006	26.02 ± 2.61	7.37 ± 0.33	2.34 ± 0.26	2.17 ± 0.25	0.53 ± 0.01
		30–60	0.185 ± 0.015	0.027 ± 0.006	22.07 ± 0.75	8.06 ± 0.95	2.61 ± 0.32	2.41 ± 0.11	0.58 ± 0.12
		60–90	0.142 ± 0.017	0.020 ± 0.007	17.22 ± 1.93	4.61 ± 0.36	3.29 ± 0.08	2.96 ± 0.15	0.75 ± 0.05

As shown in Table 2, the average UV_{253}/UV_{203} values of the leachate DOM for each treatment are 0.037 ± 0.007, 0.068 ± 0.038, and 0.035 ± 0.018 at the 0–30 cm depth, respectively; 0.032 ± 0.012, 0.020 ± 0.009, and 0.026 ± 0.008 at the 30–60 cm depth, respectively; and 0.013 ± 0.001, 0.014 ± 0.006, and 0.017 ± 0.008 at the 60–90 cm depth, respectively. The average UV_{253}/UV_{203} values of the leachate DOM for each treatment gradually decreased with the increasing soil layer depth. Compared with the T1 treatment, T3 treatment had a smaller average UV_{253}/UV_{203} value in the 0–60 cm leachate DOM, indicating that planting rape green manure was conducive to the soil's adsorption of DOM ($p < 0.05$).

3.1.2. α_{300} and α_{355}

Table 2 shows the changes in the absorption coefficients α_{300} and α_{355} of the leachate DOM in soil after freshwater leaching for different treatments. As shown in Table 2, the average values of the absorption coefficient α_{300} for the leachate DOM in each treatment were 30.78 ± 3.18 m^{-1}, 31.97 ± 6.64 m^{-1}, and 21.17 ± 6.39 m^{-1} at the 0–30 cm depth, respectively; 28.65 ± 5.08 m^{-1}, 18.90 ± 6.06 m^{-1}, and 20.85 ± 3.88 m^{-1} at the 30–60 cm depth, respectively; and 12.23 ± 1.80 m^{-1}, 14.99 ± 4.24 m^{-1}, and 15.48 ± 3.71 m^{-1} at the 60–90 cm depth, respectively. The average values of the absorption coefficient α_{300} for the leachate DOM in each treatment gradually decreased with the increasing soil layer depth, indicating a gradual decrease in the DOM concentration in the leachate. The absorption coefficient α_{300} of the leachate DOM in the same soil layer significantly fluctuated for different treatments and in different soil layers for the same treatment, indicating an uneven distribution of DOM in the soil leachate. Moreover, compared with the T1 treatment, the T3 treatment had a smaller average absorption coefficient α_{300} for the leachate DOM at the 0–60 cm depth, indicating that planting rape green manure can reduce the DOM content in the leachate ($p < 0.05$).

As shown in Table 2, the average values of the absorption coefficient α_{355} for the leachate DOM in each treatment were 10.06 ± 2.84 m^{-1}, 10.29 ± 3.60 m^{-1}, and 7.79 ± 3.39 m^{-1} at the 0–30 cm depth, respectively; 9.98 ± 2.88 m^{-1}, 5.35 ± 1.41 m^{-1}, and 7.70 ± 1.03 m^{-1} at the 30–60 cm depth, respectively; and 2.80 ± 0.72 m^{-1}, 4.18 ± 1.74 m^{-1}, and 4.49 ± 1.21 m^{-1} at the 60–90 cm depth, respectively. Overall, the average values of the absorption coefficient α_{355} for the leachate DOM in each treatment decreased with the increasing soil layer depth, indicating a gradual decrease in the CDOM concentration in the leachate with greater soil layer depth. In the 30–60 cm soil layer, the average values of the leachate DOM absorption coefficient α_{355} for T1 and T2 treatments were the highest and lowest, respectively. This suggested that planting rape green manure reduced the CDOM concentration in the 0–30 cm soil layer leachate, and planting Dongmu70 rye reduced the CDOM concentration in the 30–60 cm soil layer leachate, thereby promoting the accumulation of CDOM in the soil during freshwater leaching for salt control.

3.1.3. $SUVA_{254}$ and $SUVA_{260}$

The changes in the $SUVA_{254}$ and $SUVA_{260}$ values of the soil leachate DOM after freshwater leaching under different treatments are shown in Table 2. As shown in Table 2, the average $SUVA_{254}$ values for the leachate DOM in each treatment were 3.59 ± 0.70 $L\cdot(mg\cdot m)^{-1}$, 3.25 ± 1.10 L·(mg·m)$^{-1}$, and 2.88 ± 0.62 L·(mg·m)$^{-1}$ at the 0–30 cm depth, respectively; 3.41 ± 0.93 L·(mg·m)$^{-1}$, 2.78 ± 0.48 L·(mg·m)$^{-1}$, and 2.58 ± 0.37 L·(mg·m)$^{-1}$ at the 30–60 cm depth, respectively; and 2.74 ± 0.85 L·(mg·m)$^{-1}$, 2.42 ± 0.53 L·(mg·m)$^{-1}$, and 2.31 ± 0.60 L·(mg·m)$^{-1}$ at the 60–90 cm depth, respectively. The average SUVA$_{254}$ values for the leachate DOM in each treatment gradually decreased with the increasing soil depth, indicating a gradual reduction in the relative content of aromatic compounds in the soil leachate DOM and a decrease in the degree of aromatization with greater soil layer depths. The average values of SUVA$_{254}$ values for the leachate DOM in each soil layer were highest for the T1 treatment and lowest for the T3 treatment, indicating that planting green manure could reduce the aromatization degree of DOM in soil leachate.

The changes in the SUVA$_{260}$ values of the soil leachate DOM are shown in Table 2. As shown in Table 2, the average SUVA$_{260}$ values for the leachate DOM in each treatment were 3.26 ± 0.64 L·(mg·m)$^{-1}$, 2.96 ± 1.05 L·(mg·m)$^{-1}$, and 2.66 ± 0.57 L·(mg·m)$^{-1}$ at the 0–30 cm depth, respectively; 3.12 ± 0.88 L·(mg·m)$^{-1}$, 2.56 ± 0.45 L·(mg·m)$^{-1}$, and 2.36 ± 0.32 L·(mg·m)$^{-1}$ at the 30–60 cm depth, respectively; and 2.32 ± 0.94 L·(mg·m)$^{-1}$, 2.21 ± 0.92 L·(mg·m)$^{-1}$, and 2.10 ± 0.53 L·(mg·m)$^{-1}$ at the 60–90 cm depth, respectively. The changes in the SUVA$_{260}$ and SUVA$_{254}$ values for the leachate DOM in each treatment followed a consistent trend, gradually decreasing with the increasing soil depth, indicating a relative decrease in the hydrophobic compound content in the soil leachate DOM. The average SUVA$_{260}$ values for the leachate DOM in each soil layer were highest for the T1 treatment and lowest for the T3 treatment, indicating that planting two different types of green manure could reduce the hydrophobic components of DOM in soil leachate.

3.1.4. S_R

The changes in S_R values of soil leachate DOM after freshwater leaching with different treatments are shown in Table 2. As shown in Table 2, the average S_R values of the leachate DOM for each treatment were 0.77 ± 0.18, 0.83 ± 0.13, and 0.80 ± 0.21 at the 0–30 cm depth, respectively; 0.65 ± 0.14, 0.86 ± 0.23, and 0.65 ± 0.17 at the 30–60 cm depth, respectively; and 0.97 ± 0.10, 0.95 ± 0.16, and 0.94 ± 0.14 at the 60–90 cm depth, respectively. The S_R values of the leachate DOM for each treatment showed values greater than and less than one, indicating a mixed leachate DOM source. The average S_R value of the leachate DOM in the 60–90 cm soil layer was the largest for each treatment, indicating that the leachate DOM in this soil layer had the smallest relative molecular weight. The leachate DOM from the T2 treatment had the smallest relative molecular weight in the 0–60 cm depth range.

3.2. Distribution of Fluorescent Components in Soil Leachate DOM

We identified the fluorescent components in the soil leachate DOM, employing three-dimensional fluorescence spectroscopy combined with the PARAFAC method. The comparison of the PARAFAC model extracted with different component numbers included the nuclear consistency function, the sum of squared errors of the excitation and emission spectra, the extracted components' three-dimensional fluorescence spectra, and the residual spectra. We identified three components in the soil leachate DOM (Table 3). The fluorescent characteristic components of the DOM with their excitation/emission loadings are illustrated in Figure 1.

Table 3. DOM fluorescence components in soil-leaching solution after freshwater salt leaching.

Component	Ex/nm	Em/nm	Fluorescence Peak	Substances
C1	320	405	C	Humic-like material (visible-light fulvic acid)
C2	355	455	C	Humic-like material (humic acid)
C3	270 (290)	280	B	Protein-like material (tyrosine-like amino acids)

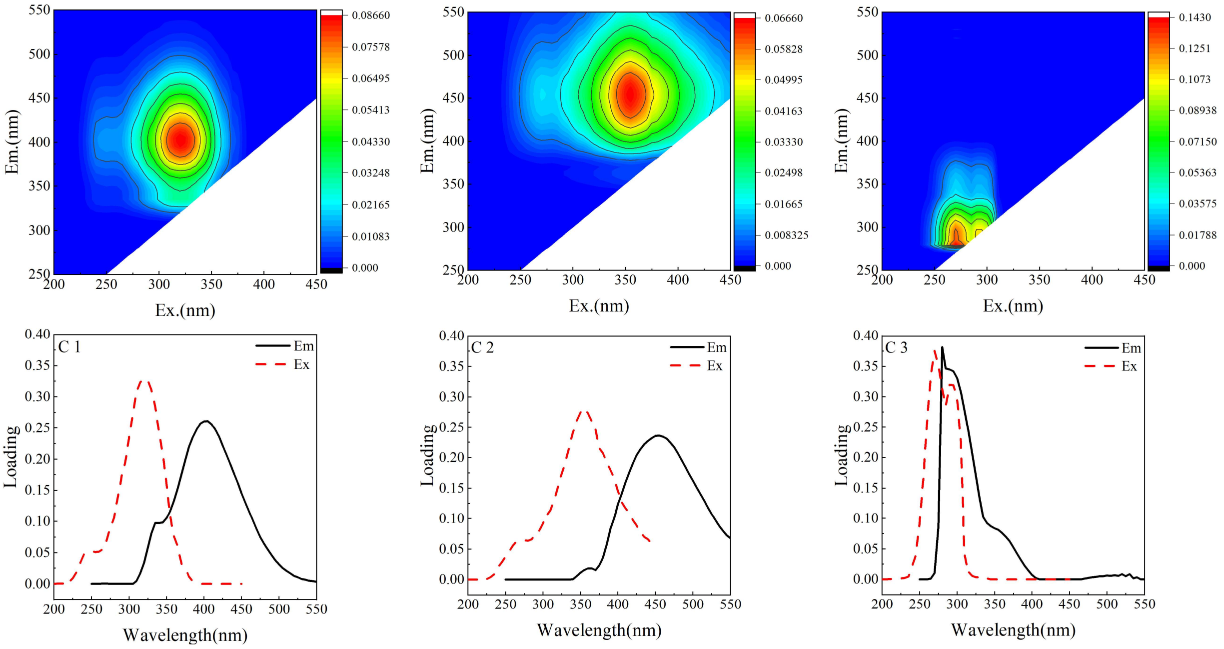

Figure 1. DOM fluorescence characteristic components and excitation/emission loads in soil leaching solutions.

According to Table 3, the EEMs-PARAFAC model identified three fluorescent components in the leachate DOM. Component 1 (C1) and component 2 (C2) were humic-like substances, while component 3 (C3) was a protein-like substance. As depicted in Figure 1, one fluorescence peak with an excitation wavelength/emission wavelength (Ex/Em) of 320 nm/405 nm was observed in the fluorescence spectra and excitation/emission loadings of component C1, corresponding to peak C. This substance represented humic-like material (visible-light fulvic acid). One fluorescence peak presented with an Ex/Em of 355 nm/455 nm in the fluorescence spectra and excitation/emission loadings of component C2, corresponding to peak C. This substance was a humic-like material (humic acid). Two fluorescence peaks were observed with Ex/Em wavelengths of 270 nm/280 nm and 290 nm/280 nm in the fluorescence spectra and excitation/emission loadings of component C3, corresponding to peak B. These substances were protein-like materials (tyrosine-like amino acids).

3.3. Relative Proportions of Fluorescent Components in Soil Leachate DOM

As depicted in Figure 2, the relative proportions of the three fluorescent components in the soil leachate DOM for T1 treatment across different soil layers showed the highest fluorescence intensity for visible-light fulvic acid, followed by tyrosine-like amino acids. Humic acid had the lowest proportion. The average proportions of the same components did not significantly vary in different soil layers.

For T2 treatment, the relative proportions of the three fluorescent components in the soil leachate DOM across different soil layers indicated the highest fluorescence intensity for visible-light fulvic acid, followed by humic acid, and tyrosine-like amino acids had the lowest proportion. Like the T1 treatment, the average proportions of the same components in different soil layers did not significantly differ. Compared with the T1 treatment, the relative proportion of the visible-light fulvic acid fluorescence intensity decreased, humic acid increased, and tyrosine-like amino acids decreased.

For the T3 treatment, the relative proportions of the three fluorescent components in the soil leachate DOM across different soil layers showed the highest fluorescence intensity for visible-light fulvic acid, followed by tyrosine-like amino acids, and humic acid had the lowest proportion. The average proportion of the visible-light fulvic acid fluorescence intensity gradually increased with the soil depth, while humic acid decreased. Additionally, the relative proportion of visible-light fulvic acid fluorescence intensity in the soil leachate DOM increased and that of humic acid decreased across different soil layers compared with the T1 and T2 treatments.

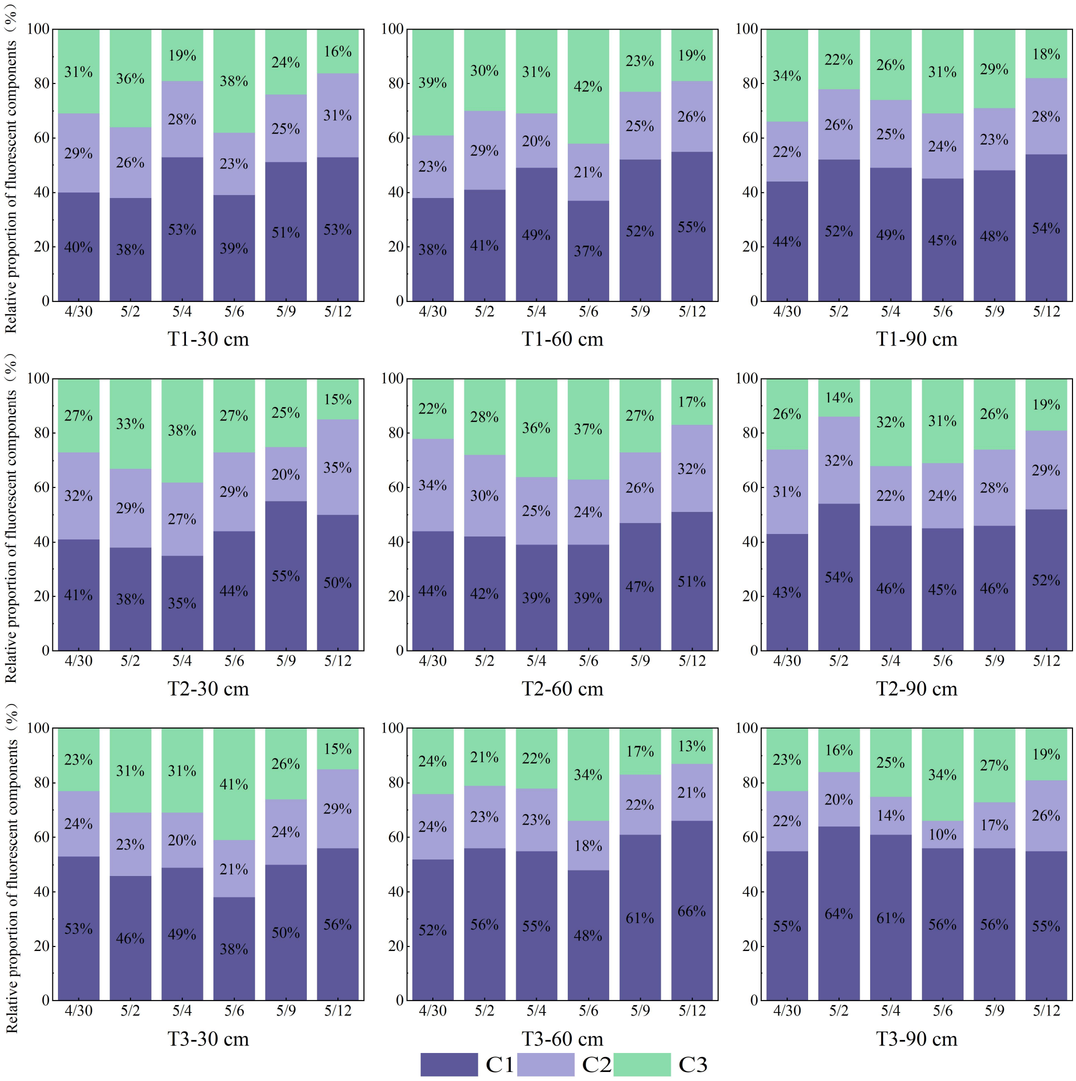

Figure 2. Relative proportion of fluorescent components of DOM in different control soil-leaching solutions.

3.4. Fluorescence Spectral Characteristics of DOM in Soil Leachates

3.4.1. FI

The changes in the fluorescence index (FI) values of the soil leachate DOM after freshwater leaching in different treatments are illustrated in Figure 3A–C. Figure 3A–C shows that the average FI values of leachate DOM for each treatment were 1.57 ± 0.06, 1.68 ± 0.10, and 1.60 ± 0.07 at the 0–30 cm depth, respectively; 1.60 ± 0.08, 1.71 ± 0.06, and 1.61 ± 0.06 at the 30–60 cm depth, respectively; and 1.78 ± 0.04, 1.75 ± 0.05, and 1.75 ± 0.08 at the 60–90 cm depth, respectively. The FI values of the leachate DOM for each treatment in different soil layers ranged from 1.4 to 1.9, indicating that the primary sources of the soil leachate DOM were a mixture of terrestrial and biological sources. Additionally, the average FI values of the leachate DOM for each treatment gradually increased with the increasing soil depth, suggesting an increasing proportion of biological sources in the leachate DOM. The average FI values of the leachate DOM for the T2 and T3 treatments were higher in the 0~60 cm soil layer compared with the T1 treatment, indicating that planting green manure could increase the proportion of biological sources in leachate DOM, thereby reducing terrestrial inputs (such as terrestrial runoff and soil leaching) ($p < 0.05$).

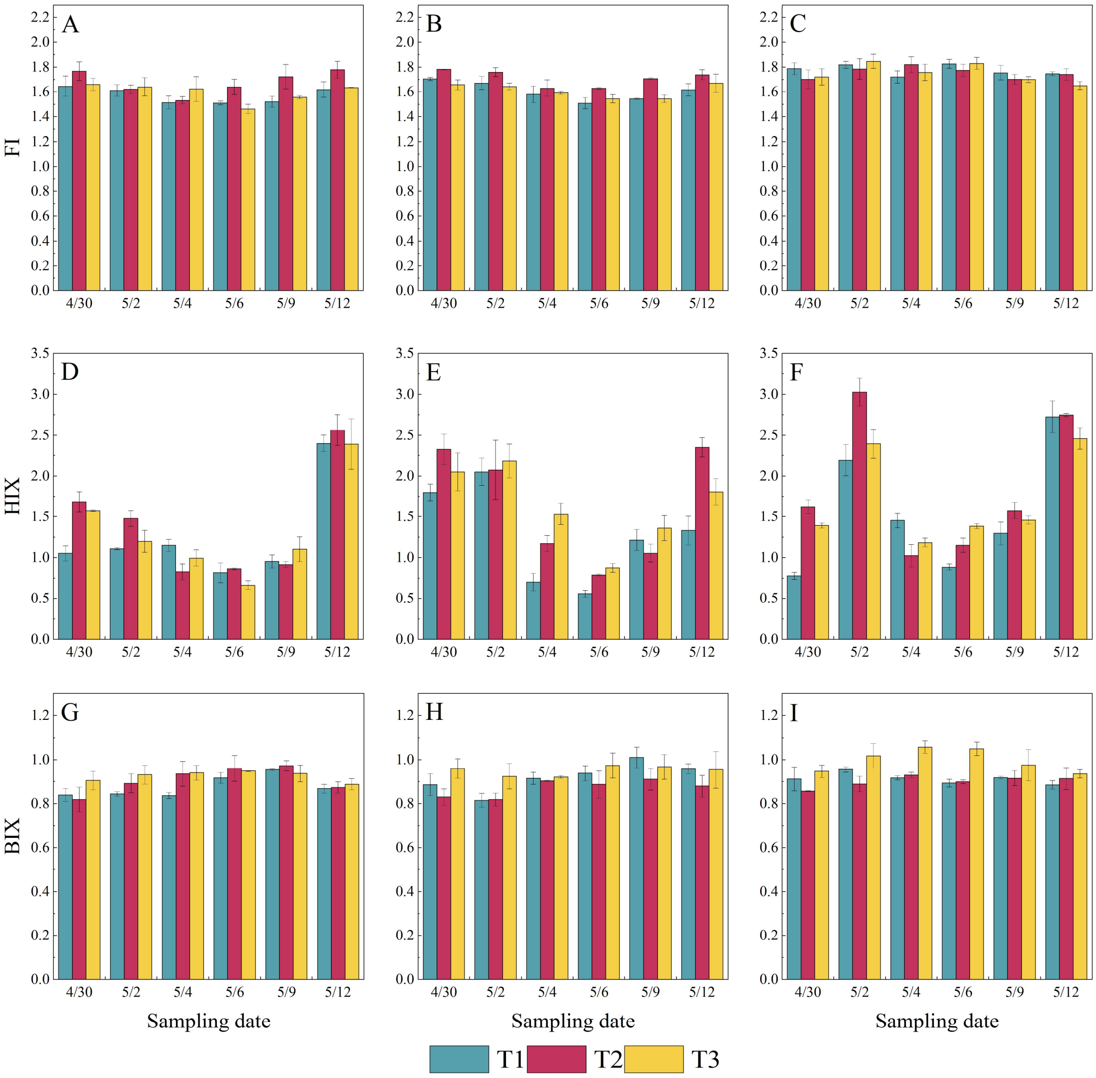

Figure 3. Fluorescence spectral characteristic components of DOM in different control soil-leaching solutions. (**A**–**C**): T1-30, 60, 90cm; (**D**–**F**): T2-30, 60, 90cm; (**G**–**I**): T3-30, 60, 90cm. T1, non-green manure treatment; T2, Dongmu70 rye treatment; T3, rape treatment.

3.4.2. HIX

The variations in the humification index (HIX) values of the soil leachate DOM after freshwater leaching in different treatments are depicted in Figure 3D–F. According to Figure 3D–F, the average HIX values of the leachate DOM for each treatment were 1.25 ± 0.58, 1.39 ± 0.68, and 1.32 ± 0.60 at the 0–30 cm depth, respectively; 1.28 ± 0.59, 1.63 ± 0.70, and 1.63 ± 0.48 at the 30–60 cm depth, respectively; and 1.55 ± 0.76, 1.86 ± 0.84, and 1.71 ± 0.56 at the 60–90 cm depth, respectively. The HIX values of the leachate DOM for each treatment in the different soil layers were all below four, indicating a relatively low humification degree and poor stability in the leachate DOM. Additionally, the average HIX values of the leachate DOM for each treatment gradually increased with the increasing soil depth, indicating an elevation in the humification degree and stability of the leachate DOM. The graph also demonstrates that the trends in the HIX values for the leachate DOM from the three treatments at different sampling periods were consistent between each soil layer. The average HIX values of the leachate DOM for the T2 and T3 treatments were higher in the same soil layer compared with the T1 treatment, indicating that planting green manure could enhance the humification degree and stability of leachate DOM, thereby improving the soil's humification degree ($p < 0.05$).

3.4.3. BIX

The changes in biological index (BIX) values of the soil leachate DOM after freshwater leaching in different treatments are displayed in Figure 3G–I. According to Figure 3G–I, the average BIX values of the leachate DOM for each treatment were 0.88 ± 0.05, 0.91 ± 0.06, and 0.92 ± 0.02 at the 0–30 cm depth, respectively; 0.92 ± 0.07, 0.87 ± 0.04, and 0.95 ± 0.02 at the 30–60 cm depth, respectively; and 0.91 ± 0.02, 0.90 ± 0.03, and 1.00 ± 0.05 at the 60–90 cm depth, respectively. The BIX values of the leachate DOM for each treatment in the different soil layers mostly fell between 0.8 and 1.0, indicating a substantial contribution of recently autochthonous sources induced by microorganisms in the leachate DOM and reflecting a moderate level of autochthonous characteristics. Additionally, the average BIX values of the leachate DOM for T1 and T2 treatments showed little difference with the increasing soil depth; meanwhile, the differences in the average BIX values gradually increased with the soil depth for T3 treatment. In the same soil layer, the average BIX values for T3 treatment were higher than those for T1 and T2 treatments. This suggests that planting rapeseed could enhance the autochthonous sources in leachate DOM ($p < 0.05$).

4. Discussion

This study characterized soil leachate dissolved organic matter (DOM) under three treatments—T1, T2 and T3 treatments—using ultraviolet (UV) characteristic parameters such as UV_{254}, UV_{253}/UV_{203}, α_{300}, α_{355}, $SUVA_{254}$, $SUVA_{260}$, and S_R, as well as fluorescence parameters including FI, HIX, and BIX, coupled with parallel factor analysis. The average values of the UV_{254}, UV_{253}/UV_{203}, α_{300}, α_{355}, $SUVA_{254}$, $SUVA_{260}$, and S_R characteristic parameters of the soil leachate DOM gradually decreased with the soil depth under all treatments, similar to the results found in related studies on soil DOM [29,30]. This suggests that the leachate and soil DOM shared features, indicating their migratory characteristics. The decreases in the large molecular substances, benzene ring substitution degree, colored dissolved substances, aromatization degree, and hydrophobic components in the soil leachate DOM with the increasing soil depth might be attributed to the formation of complexes between the DOM and metal ions in the soil during the downward migration of water, thereby reducing the aromatization degree and hydrophobic components in the lower-layer soil leachate DOM [31]. The T3 treatment showed lower average values for multiple parameters of the soil leachate DOM than the T1 treatment, especially at depths of 0–60 cm, indirectly indicating that planting rape as green manure enhanced the soil DOM. Additionally, the average values of the S_R characteristic parameters of the leachate DOM for all three treatments were highest in the 60–90 cm soil layer, indicating that the DOM in this soil layer had a relatively small molecular weight and low humification degree.

It was discovered that the DOM under each treatment comprised three fluorescence components via the combined three-dimensional fluorescence and parallel factor analysis. These included two humic-like components, C1 (visible-light fulvic acid) and C2 (humic acid), and one protein-like component, C3 (tyrosine-like amino acid). Analyzing the fluorescence intensity proportion for the three components revealed that the leachate DOM predominantly consisted of the C1 component under each treatment. This suggested that the leachate DOM had a high content of fulvic acid-like substances, aligning with the observation that soil humic substances have a high fulvic acid content. A previous study on the spectral characteristics of DOM in soil leachates under reclaimed water irrigation found only one humic-like peak in the leachate DOM, suggesting that other components such as amino acids and tyrosine-like amino acids might be retained in the soil system [17]. In this study, the proportion of humic acids and tyrosine-like amino acids in the leachate was relatively small, indicating that they might also be retained by the soil or the root system of green manure.

The average values of the fluorescence parameter FI for the soil leachate DOM under each treatment in the different soil layers ranged between 1.4 and 1.9, indicating mixed terrestrial and microbial sources of the leachate DOM. The average FI values for the leachate DOM under the two green manure treatments were higher in the 0–60 cm soil layer, suggesting that planting green manure can increase the proportion of microbial sources in leachate DOM, thereby reducing terrestrial inputs and minimizing DOM leaching. This was consistent with the results for the ultraviolet parameter S_R. Studies have shown that terrestrial DOM has a complex structure, with a high aromatization degree and higher content of large molecular substances, while microbial-source DOM has a simpler structure and is more easily degraded [32].

The average values of the fluorescence parameter BIX for the soil leachate DOM under each treatment in the different soil layers ranged between 0.8 and 1.0, indicating that the leachate DOM was largely influenced by microbial-induced recently autochthonous sources, displaying a moderate intensity of autochthonous characteristics. The average values of the fluorescence parameter HIX for the soil leachate DOM under each treatment in the different soil layers were all less than four, indicating a very low degree of humification in the soil leachate DOM. This contrasted with a study on cultivated land soil DOM, where the HIX was approximately ten, exhibiting strong humification characteristics [4]. This disparity might be attributed to the different soil types in the studied areas or potential discrepancies between the soil DOM and soil leachate DOM expressions.

The correlation analysis revealed a significant positive correlation ($p < 0.05$) between HIX and FI for the leachate DOM, indicating that the higher the proportion of microbial sources, the higher the humification degree. This contradicted the significant negative correlation between FI and HIX ($p < 0.01$) found in other studies [33,34]. This could be caused by the very low humification degree in the leachate DOM in this study or the inherently low humification degree in saline–alkali soil. This requires further investigation for a precise determination of the reasons.

The intrinsic differences in DOM in soil leachate after salt leaching irrigation due to green manure planting provide a theoretical basis for the sustainable development of saline–alkali land agriculture in areas with salt leaching irrigation. In this study, green manure planting could reduce the leaching loss of soluble organic matter in the soil to some extent during salt leaching irrigation, with rape green manure having the best effect [35]. Therefore, planting and incorporating green manure in saline–alkali land could achieve long-lasting and stable desalination effects, while also promoting soil and water conservation and the ecological balance of farmland in saline–alkali areas.

5. Conclusions

The average values of the ultraviolet characteristic parameters UV_{254}, UV_{253}/UV_{203}, α_{300}, α_{355}, $SUVA_{254}$, and $SUVA_{260}$ for the soil leachate dissolved organic matter (DOM) gradually decreased with the soil layer depth. This indicated that the large molecular substances, benzene ring substitution degree, colored dissolved organic matter, aromatization degree, and hydrophobic components in the soil leachate DOM decreased with the increasing soil depth. Compared with the T1 treatment, both the green manure treatments reduced the relative molecular weight, aromatization degree, hydrophobic components, and colored organic matter concentration in the leachate DOM. This suggests that green manure planting can reduce the leaching of soluble organic matter in the soil during leaching irrigation, with rape green manure exhibiting better results. The soil leachate DOM was characterized by three fluorescence components under all treatments and in the different soil layers, including two humic-like components (C1: visible-light fulvic acid; C2: humic acid) and one protein-like component (C3: tyrosine-like amino acids). The visible-light fulvic acid component had the highest proportion. The combined contribution of the two humic-like components (C1 + C2) was approximately 70%, indicating that the leachate DOM was dominated by humic substances. Analysis of the fluorescence parameters FI, HIX, and BIX of the soil leachate DOM revealed that the proportions of biological sources and the humification degree of the leachate DOM were relatively higher under both green manure treatments than the non-green manure treatment. This implies that planting green manure could reduce the proportion of terrestrial leachate DOM and enhance soil humification.

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References

1. Dong, H.Y.; Zhu, Z.L.; Li, X.H.; Yang, L.P.; Zhang, Z. Analysis on Distribution, Utilization Status and Governance Effect of Saline-Alkali Soil in Shandong Province. *Shandong Agric. Sci.* **2017**, *49*, 134–139.
2. Zhao, Q.; Zhang, X.J.; Ning, X.G.; Cao, W.D. Influence of winter green manure on wind erosion in farmland of north China. *J. Arid Land Resour. Environ.* **2016**, *30*, 120–124.
3. Song, X.; Su, Y.; Zheng, J.; Zhang, Z.; Liang, Z.; Tang, Z. Study on the effects of salt tolerance type, soil salinity and soil characteristics on the element composition of Chenopodiaceae halophytes. *Plants* **2022**, *11*, 1288. [CrossRef] [PubMed]
4. Ma, Q.Q.; Li, G.; Wei, Y. Spectral characteristics and spatiotemporal variation of DOM in Peri-urban Critical Zone. *Environ. Chem.* **2020**, *39*, 455–466.
5. McIntyre, A.M.; Guéguen, C. Binding interactions of algal-derived dissolved organic matter with metal ions. *Chemosphere* **2013**, *90*, 620–626. [CrossRef] [PubMed]
6. Li, Q.F.; Kong, F.L.; Xi, M.; Li, Y. Leaching of soil salt with different leaching water volumes in aquaculture ponds of Jiaozhou Bay. *Chin. J. Ecol.* **2018**, *37*, 1127–1134.
7. Mcdowell, W.H. Dissolved organic matter in soils-future directions and unanswered questions. *Geoderma* **2003**, *113*, 179–186. [CrossRef]
8. Kalbitz, K.; Solinger, S.; Park, J.-H.; Michalzik, B.; Matzner, E. Controls on the dynamics of dissolved organic matter in soils: A review. *Soil Sci.* **2000**, *165*, 277–304. [CrossRef]
9. Rattan, L. Soil erosion and the global carbon budget. *Environ. Int.* **2003**, *29*, 437–450.
10. Kalbitz, K.; Schmerwitz, J.; Schwesig, D.; Matzner, E. Biodegradation of soil-derived dissolved organic matter as related to its properties. *Geoderma* **2003**, *113*, 273–291. [CrossRef]
11. McDowell, W.H.; Currie, W.S.; Aber, J.D.; Yano, Y. Effects of chronic nitrogen amendments on production of dissolved organic carbon and nitrogen in forest soils. *Water Air Soil Pollut.* **1998**, *105*, 175–182. [CrossRef]
12. Williams, B.L.; Edwards, A.C. Processes influencing dissolved organic nitrogen, phosphorus and sulphur in soils. *Chem. Ecol.* **1993**, *8*, 203–215. [CrossRef]
13. Zhou, J.; Chen, H.; Huang, W. Effects of rice straw-derived dissolved organic matter on pyrene sorption by soil. *Environ. Toxicol. Chem.* **2010**, *29*, 1967–1975. [CrossRef] [PubMed]
14. Cao, C.L.; Liang, M.Q.; He, G.Y.; Zong, Y.N.; Tang, J.F. Fluorescent Dissolved Organic Matter and Its Correlation with Water Quality in a Urban River: A Case Study of the Lujiang River in Beilun Ningbo. *Environ. Sci.* **2018**, *39*, 1560–1567.
15. Wang, C.Y.; Zhou, J.B.; Wang, X.; Xia, Z.M. Contents and Biodegradation of Soluble Organic Carbon in Different Plant Residues from the Loess Plateau. *Environ. Sci.* **2011**, *32*, 1139–1145.
16. Zhou, S.; Sun, Y.; Zhang, Y.; Zhan, J.; Wang, H.; Huang, T.; Cong, H.; Cui, J.; Li, Z. Seasonal variations of ultraviolet-visible and excitation emission matrix spectroscopy characteristics of overlying water dissolved organic matter in Zhoucun Reservoir, Shandong Province. *J. Lake Sci.* **2019**, *31*, 1344–1356.
17. Fan, C.H.; Xin, Y.B.; Yuan, W.J. Spectral Characteristics of Dissolved Orqanic Matter (DOM) in Leachate Released From Agricultural Soil Irrigated With Reclaimed Water. *Spectrosc. Spectr. Anal.* **2022**, *42*, 2432–2436.
18. Musadji, N.; Lemée, L.; Caner, L.; Porel, G.; Poinot, P.; Geffroy-Rodier, C. Spectral characteristics of soil dissolved organic matter: Long-term effects of exogenous organic matter on soil organic matter and spatial-temporal changes. *Chemosphere* **2020**, *240*, 124808. [CrossRef] [PubMed]
19. Gao, J.; Liang, C.; Shen, G.; Lv, J.; Wu, H. Spectral characteristics of dissolved organic matter in various agricultural soils throughout China. *Chemosphere* **2017**, *176*, 108–116. [CrossRef]

20. Qin, W.D.; Jia, L.M.; Liu, Z.K.; Zhi, J.F.; Cao, W.D. Effect of Cultivar of Winter Green Manure and Seeding Method on Soil Nutrients and Quality and Yield of Sequent Peanut. *Acta Agric. Boreali-Sin.* **2015**, *30*, 168–172.
21. Zhu, X.; Wen, Z.; Zhao, B.; Liu, C.; Xing, J.; Dong, J.; Ding, H.; Hong, L. Effects of Planting Green Manure on Dynamic Changes of Saline Soil Nutrients and Soluble Salt Ions. *Southwest China J. Agric. Sci.* **2017**, *30*, 1894–1898.
22. Li, Z.S.; Lian, X.J.; Wang, W.; Zhao, T.K.; Li, H.J. Research progress of green manure in China. *Pratacultural Sci.* **2013**, *30*, 1135–1140.
23. Subaedah, S.; Aladin, A.; Nirwana. Fertilization of nitrogen, phosphor and application of green manure of Crotalaria juncea in increasing yield of maize in marginal dry land. *Agric. Agric. Sci. Procedia* **2016**, *9*, 22–25. [CrossRef]
24. Li, H.; Fan, Z.; Wang, Q.; Wang, G.; Yin, W.; Zhao, C.; Yu, A.; Cao, W.; Chai, Q.; Hu, F. Green manure and maize intercropping with reduced chemical N enhances productivity and carbon mitigation of farmland in arid areas. *Eur. J. Agron.* **2023**, *145*, 126788. [CrossRef]
25. Weishaar, J.L.; Aiken, G.R.; Bergamaschi, B.A.; Fram, M.S.; Fujii, R.; Mopper, K. Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon. *Environ. Sci. Technol.* **2003**, *37*, 4702–4708. [CrossRef] [PubMed]
26. Hua, B.; Veum, K.; Yang, J.; Jones, J.; Deng, B. Parallel factor analysis of fluorescence EEM spectra to identify THM precursors in lake waters. *Environ. Monit. Assess.* **2010**, *161*, 71–81. [CrossRef] [PubMed]
27. Ohno, T. Fluorescence inner-filtering correction for determining the humification index of dissolved organic matter. *Environ. Sci. Technol.* **2002**, *36*, 742–746. [CrossRef] [PubMed]
28. Cory, R.M.; Miller, M.P.; McKnight, D.M.; Guerard, J.J.; Miller, P.L. Effect of instrument-specific response on the analysis of fulvic acid fluorescence spectra. *Limnol. Oceanogr. Methods* **2010**, *8*, 67–78.
29. Kaiser, K.; Kalbitz, K. Cycling downwards-dissolved organic matter in soils. *Soil Biol. Biochem.* **2012**, *52*, 29–32. [CrossRef]
30. Sanderman, J.; Amundson, B.R. Dissolved organic carbon chemistry and dynamics in contrasting forest and grassland soils. *Biogeochemistry* **2008**, *89*, 181–198. [CrossRef]
31. Liang, K. The Optical Characteristics and Influencing Factors of Soil DOM in Purple Soil Area under Different Land Uses. Master's Thesis, Southwest University, Chongqing, China, 2020.
32. Oili, K.; Veikko, K.; Aino, S. Chemical and biological characterization of dissolved organic matter derived from Norway spruce litter divided into fractions according to molecular size. *Eur. J. Soil Biol.* **2012**, *50*, 109–111.
33. Qin, X.Q. Study on the Composition and Characteristics of Dissolved Organic Matter (DOM) in Soil under Different Land Uses by Using Fractionation, Spectral and Chromatographic Techniques. Master's Thesis, South China Agricultural University, Guangzhou, China, 2019.
34. Li, Y. Composition, Spectral Characteristics and Source Analysis of Soils in Different Land Use Types. Master's Thesis, Xi'an University of Architecture and Technology, Xi'an, China, 2021.
35. Wang, Y.; Kang, S.; Li, F.; Zhang, L.; Zhang, J. Saline water irrigation scheduling through a crop-water-salinity production function and a soil-water-salinity dynamic model. *Pedosphere* **2007**, *17*, 303–317. [CrossRef]