land

MDPI

Article

Response of Soil Organic Carbon and Its Components to Alpine Wetland Degradation in Arid Central Asia

Maidinuer Abulaizi [1,2], Mo Chen [1,2], Yuxin Tian [1], Yunpeng Hu [3], Dongliang Han [4], Yang Hu [3], Jianqin Zhou [3], Zailei Yang [3] and Hongtao Jia [2,3,*]

[1] College of Grassland Science, Xinjiang Agricultural University, Urumqi 830052, China; 320220035@xjau.edu.cn (M.A.); 320200062@xjau.edu.cn (M.C.); 320210034@xjau.edu.cn (Y.T.)
[2] Xinjiang Key Laboratory of Soil and Plant Ecological Processes, Xinjiang Agricultural University, Urumqi 830052, China
[3] College of Resources and Environment, Xinjiang Agricultural University, Urumqi 830052, China; 320212555@xjau.edu.cn (Y.H.); hy@xjau.edu.cn (Y.H.); machine1229@xjau.edu.cn (J.Z.); yzl@xjau.edu.cn (Z.Y.)
[4] College of Atmospheric Sciences, Lanzhou University, Lanzhou 730000, China; handl@lzu.edu.cn
* Correspondence: jht@xjau.edu.cn

Abstract: Soil organic carbon (SOC) is composed of carbon components with different stabilities, which is affected by wetland degradation. Understanding the impact of wetland degradation on SOC dynamics provides a basis for the sustainable utilization of wetlands. Here, soils were collected from different degraded areas of the Bayinbuluk alpine wetland—including one non-degraded (ND), one slightly degraded (SD), and one heavily degraded region (HD)—and the effects of degradation on SOC and its components were measured using the sulfuric acid oxidation method (a modified Walkley–Blak method) with different concentrations. The results showed the following: (1) At 0–100 cm of soil, the average total SOC in the ND area was 93.45 g/kg, while that in the SD and HD areas was decreased by 48.7% and 82.0%, respectively. (2) Under ND, SD, and HD, the contents of the very labile OC component (F1) were 29%, 28% and 14%, respectively; those of the labile OC component (F2) were 8%, 8% and 8%, respectively; those of the less labile OC component (F3) were 6%, 7% and 15%, respectively; and those of the recalcitrant OC component (F4) were 57%, 57% and 63%, respectively. (3) There are significant correlations between organic carbon (OC) and its components ($p < 0.01$), and the proportions of F2, F3, and F4 in SOC are 31%, 7%, 4%, and 58%, respectively. Meanwhile, F4 is the main component in three areas, and the proportion of unstable organic carbon components increases with the aggravation of degradation. Therefore, wetland degradation affects the SOC content and its components, as well as reducing the SOC stability.

Keywords: degraded wetland; SOC fractions; carbon management index; SOC stability

check for updates

Academic Editor: Yongheng Gao

Received: 14 January 2025
Revised: 4 February 2025
Accepted: 11 February 2025
Published: 12 February 2025

Citation: Abulaizi, M.; Chen, M.; Tian, Y.; Hu, Y.; Han, D.; Hu, Y.; Zhou, J.; Yang, Z.; Jia, H. Response of Soil Organic Carbon and Its Components to Alpine Wetland Degradation in Arid Central Asia. *Land* **2025**, *14*, 387. https://doi.org/10.3390/land14020387

1. Introduction

Wetlands store about 20–30% of soil carbon, thus playing an important role in reducing CO_2 and CH_4 emissions [1]. In recent years, influenced by natural and anthropogenic factors, the ecological function and ecosystem stability of alpine wetlands have faced serious threats [2]. Bayinbuluk alpine wetland, as an area of world natural heritage, plays a key role as an ecological barrier in arid areas of Central Asia and is an extremely important "air wet island" [3]. However, from 1986 to 2021, the degraded area of Bayinbuluk Grassland reached 39.49% [4].

Due to the natural hydrothermal conditions, alpine wetlands store significant amounts of organic carbon [5,6]. Considering the direct relationship with the atmospheric C pool, a slight change in the wetland soil C pool has a positive feedback effect on global warming [7]. Hence, it is significant to analyze the change in SOC content and its influencing factors in order to study regional environmental change and carbon cycles [8]. The change in soil moisture is the most intuitive phenomenon associated with wetland degradation. A decrease in soil moisture (SM) content will significantly change the vegetation coverage and biomass, directly affecting the SOC content [9–12]. Some scholars conducted a dynamic study on the SOC content of a wet meadow in Gahai Wetland Nature Reserve (in the eastern part of Qinghai–Tibet Plateau) and came to the conclusion that, due to serious water and vegetation degradation, the SOC loss rate of the wet meadow is as high as 50%, resulting in serious damage to the carbon sink capacity of the wetland [13]. This indicates that the degradation of wetlands is a key factor affecting the balance between SOC input and loss. Compared with research on the change in total OC, the change in OC composition helps us to better understand the response mechanism of OC to degradation [14–16]. The ratio of active OC to total OC is very small, but its sensitivity to changes in the soil environment is higher than that of total OC. The stable OC composition is an important index of the soil C pool, which can determine the storage of OC [17,18]. In addition, when vegetation coverage was reduced by 81% in an alpine region, the active OC content in the topsoil was reduced by 38.40–86.70% [19,20]. However, few studies have focused on the response of stable carbon fractions to wetland degradation. Given the feedback effects of SOC and its fraction changes on global warming and their importance in improving the sustainability of wetlands, it is particularly important to understand their changes at different levels of degradation.

Soil carbon is affected by soil physiochemical properties [21]. As such, soil moisture has an important influence on the formation and mineralization of organic carbon [22–25]. It has been reported that, in Alaska, the carbon sink function of swamp wetlands increases or decreases with an increasing or decreasing water level, respectively [26]. The study also showed that the high porosity of sandy soil leads to reductions in the water and salt contents, which accelerates the decomposition of SOC, while clay contributes to the accumulation of OC due to its high water and salt contents [27]. Hence, it is significant to determine the changes in soil C in order to further understand the carbon cycle for research on carbon sink management for wetland ecosystems.

The stability of the soil C sink in Bayinbuluk alpine wetland plays an important role in the stability of regional ecosystems. When considering the long-term storage of OC, the stability of the C content in the soil is a key factor [28,29]. At the same time, understanding the influence of the SOC content in different stability degradation areas will help us to better understand the response of SOC to degradation [14,30]. To date, some scholars have evaluated the stability of SOC from the perspective of the SOC continuum [31]. However, it has not been confirmed whether the stability of organic carbon and its influencing factors can be considered as a continuum in degraded alpine wetland soil in arid areas. In recent years, the improved Walkley–Black method has been used to separate organic carbon, which is regarded as a continuum of organic carbon, into four continuous fractions (i.e., very labile, labile, less labile, and recalcitrant organic carbon), providing ideal results [14,30,31]. Based on this, the changes in SOC and its components in the Bayinbuluk wetland under different degradation levels (non-degraded, slightly degraded, and heavily degraded) were understood, and the stability of SOC was evaluated through these components. For example, Yu et al. evaluated the influence of vegetation degradation on SOC stability through the instability index and pointed out that grassland degradation influenced the stability of soil SOC [30]. In this study, for the first time, we assessed the stability of SOC and its components in alpine wetland soils under different degradation levels in arid regions using a modified Walkley–Black method, providing basic data for understanding the cycle process of soil organic carbon in alpine wetland in the arid region of Central Asia. Therefore, the primary objectives of this study were to (1) analyze the dynamics of total SOC and its oxidizable fractions under different degradation areas, and (2) evaluate the effect of wetland degradation on SOC stability.

2. Materials and Methods

2.1. Study Site

The research area is located in the Bayinbuluk Swan National Nature Reserve in Xinjiang. The wetland covers an area of about 770 km^2, is at an altitude of 2410 m, and has an annual average temperature of −4.6 °C [9]. Precipitation is low (273 mm), while evaporation is high (1250 mm). The dominant plant groups are ND: *Carex tristachya; Potentilla serices*; SD: *Festuca ovina*; and HD: *Leymus*. According to the surface water, vegetation types (total vegetation coverage, aboveground biomass, vegetation coverage of *Gramineae* and *Cyperaceae*) and grazing intensity, alpine wetlands with varying degrees of degradation are divided into swamps (ND), swamp meadows (SD), and desert (HD). Table 1 and Figure 1 summarize the overall situation of wetland degradation in the area [9].

Table 1. Basic situation of study area.

Area	Plant Coverage (%)	Plant Height (cm)	Aboveground Biomass ($g\ m^{-2}$)	Plant Species Richness	Grazing Intensity (Head hm^{-2})	Buluk Density ($g\ cm^{-3}$)	Soil Moisture (%)
ND	85.00	48.60	107.33 ± 23.92	12	0.65	0.40	124.20
SD	70.00	8.20	55.73 ± 3.23	8	2.09	0.56	80.57
HD	15.00	5.50	10.20 ± 0.83	1	4.15	1.41	17.25

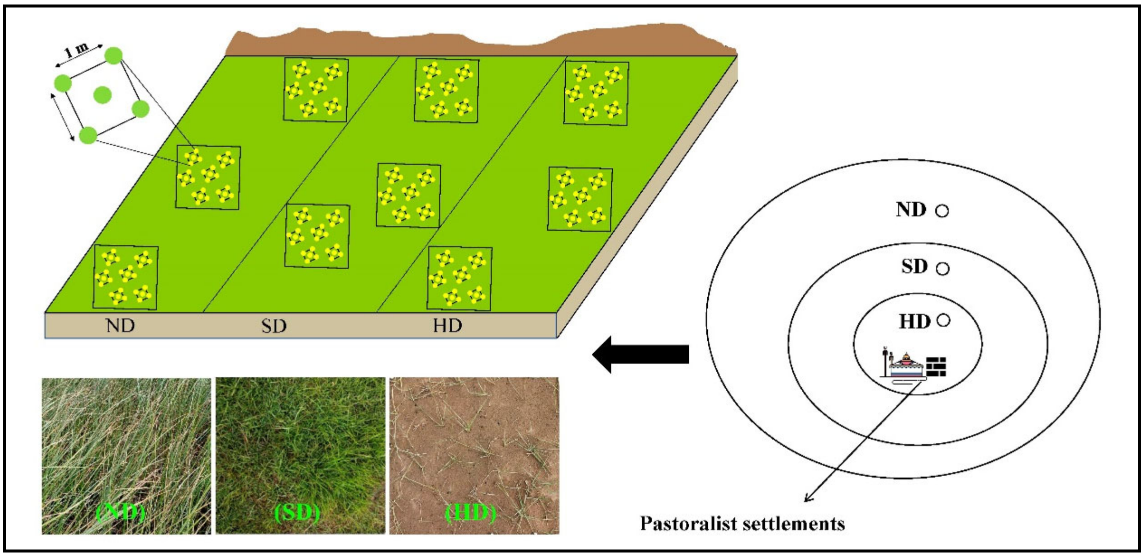

Figure 1. Study area and sampling plots.

2.2. Soil Samples

Here, 3 large quadrats (50 × 50 m) were randomly set in each area, and 6 small quadrats (1 × 1 m) were randomly selected from each large quadrat, for a total of 18 sub-quadrats. After removing the surface plants and litter, soil samples from six depths (0–10, 10–20, 20–30, 30–50, 50–70, and 70–100 cm) were collected within the quadrats using a soil drill (d = 7 cm); see Figure 1. Five samples collected at the same depth were evenly mixed, and 108 composite samples were obtained. The samples obtained were divided into two sub-samples. After drying to remove plant residues and other impurities, they were screened at 1 and 0.25 mm, then used to determine the OC and its fractions in soil. The last sample was treated as a spare sample.

2.3. Laboratory Analysis

The SOC content was measured using the $K_2Cr_2O_7$-H_2SO_4 oxidation method [30]. The OC of different oxidation conditions was determined using the improved Walkley–Black method [15,32,33]. In this method, different concentrations of sulfuric acid (6, 9, and 12 mol/L) were used to determine the oxidizable C content [15]. According to the oxidation capacity, OC can be divided into four groups: (F1) very labile OC, (F2) labile OC, (F3) less labile OC, and (F4) recalcitrant OC (Figure 2).

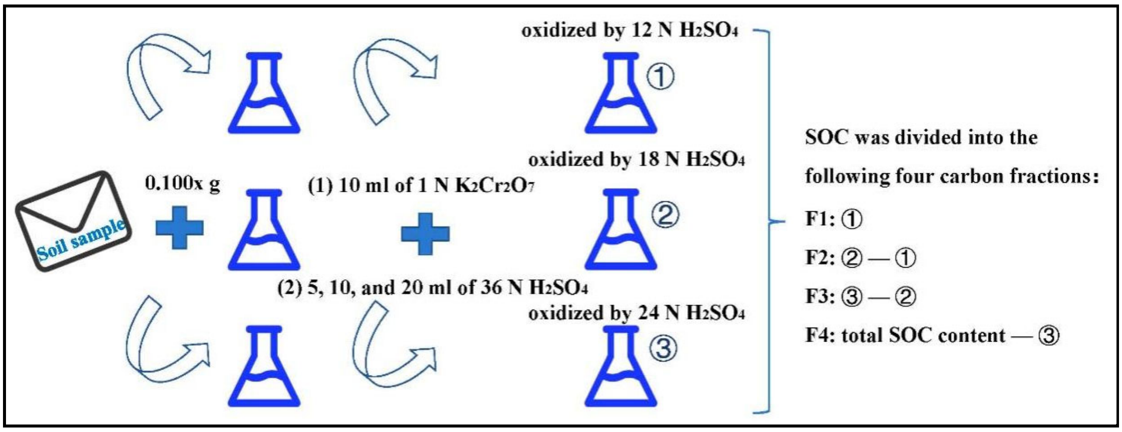

Figure 2. Method of grouping organic carbon fractions.

The carbon pool management index (CMI) is calculated as follows:

$$\text{CPI(Carbon pool index)} = \frac{\text{sample total OC (g/kg)}}{\text{reference sample total C (g/kg)}} \quad (1)$$

$$\text{LI(Lability index)} = \frac{\text{Lability of C in sample soil}}{\text{Lability of C in reference soil}} \quad (2)$$

$$\text{Lability of SOC} = \frac{\text{F1}}{\text{Total SOC} - \text{F1}} \quad (3)$$

$$\mathbf{CMI} = \mathbf{CPI} \times \mathbf{LI} \times 100 \quad (4)$$

2.4. Statistical Analyses

We used SPSS 17.0, Sigma plot 10.0, and R (version 4.0.2) for statistical analysis and plotting. At the 95% significance level, the LSD test was used to compare the average values of different degraded areas, the soil depth, and the physiochemical properties of the soil, and to test the normality and uniformity of variance. The relationships between organic carbon and its fractions were determined through linear regression analysis.

3. Results

3.1. Distribution Characteristics of SOC in Different Degradation Areas

As shown in Figure 3, the content of SOC in the 0–50 cm soil layers decreased significantly with the aggravation of degradation ($p < 0.05$), but there was no significant difference between the SD and HD areas at 50–70 cm ($p > 0.05$). In ND and SD areas, the SOC content at a 20–30 cm depth was significantly higher than that in other soil layers; however, in the HD area, the SOC content at a depth of 0–10 cm (20.64 ± 1.05 g kg^{-1}) was significantly higher than that at the other depths. Moreover, there was no significant difference in the SOC content between the 10–20 (18.34 ± 0.98 g kg^{-1}) cm and 20–30 (18.47 ± 1.45 g kg^{-1}) cm depths in the HD area, but it was significantly higher than in the 30–50 cm, 50–70 cm and 70–100 cm soil layers. With increasing soil depth, the soil in the ND and SD areas showed a trend of rising first and then falling, while the soil in the HD area showed a gradual declining trend.

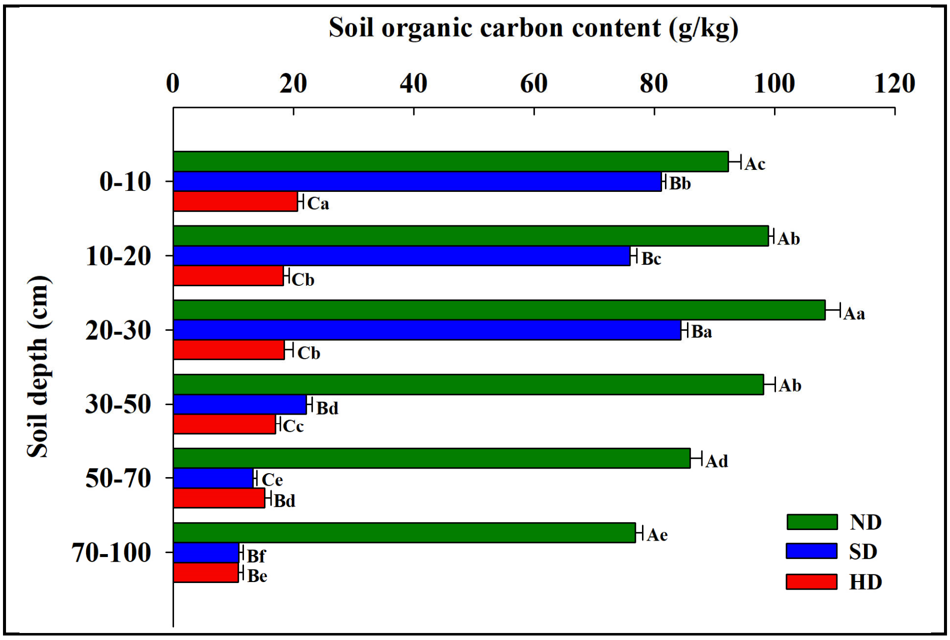

Figure 3. Contents of SOC under different wetland degradation levels. At a 95% significance level, there are significant differences in different degraded areas (uppercase letters) and different depths (lowercase letters).

3.2. Distribution of OC Fractions Under Different Degradation Areas

With the aggravation of degradation, the organic carbon content of F1 decreased significantly in all soil layers ($p < 0.05$), and the change in the SOC content of F2 in the 20–30 cm soil layers was significantly lower in HD areas than in ND and SD areas (Table 2). All other soil layers decreased significantly with the aggravation of degradation ($p < 0.05$). The F3 component increased significantly at first, then decreased significantly in the 0–10 cm soil layer, and decreased significantly in the 10–30 cm soil layer. The content of organic carbon in the ND region in the 30–100 cm soil layer was significantly higher than that in the SD and HD areas ($p < 0.05$). The F4 component in the ND and SD areas in the 0–10 cm soil layers was significantly higher than that in the HD areas. Furthermore, the F4 component in the 10–30 cm soil layers was significantly lower with the aggravation of degradation, and the F4 component in the 30–100 cm soil layers was significantly higher than that in the HD and SD areas ($p < 0.05$). In summary, the content of each component of SOC is affected by wetland degradation and the soil depth (Table 2). Therefore, when studying the content of SOC components in wetlands, it is necessary to comprehensively consider the impacts of wetland degradation and soil depth to more fully understand the dynamic changes in SOC.

Table 2. SOC content in soil layers from 0 to 100 cm. The results are expressed as the average value (±SE). Different uppercase letters in the rows (degradation degree), lowercase letters in the columns (soil depth), and Greek letters in the columns (SOC component) indicate significant differences at $p < 0.05$.

Soil Depth	Non-Degradation (ND)	Slight Degradation (SD)	Heavy Degradation (HD)
(cm)		(g kg^{-1})	
	Fraction 1 (F1: Very labile organic carbon fraction)		
0–10	21.89(±1.46) Adβ	17.28(±0.79) Bcβ	4.44(±0.40) Caβ
10–20	27.40(±1.01) Acβ	22.52(±0.54) Bbβ	3.04(±0.56) Cbβ
20–30	31.38(±0.67) Aaβ	24.72(±1.17) Baβ	2.94(±0.48) Cbβ
30–50	28.79(±1.28) Abβ	6.05(±0.99) Bdβ	2.01(±0.65) Ccβγ
50–70	27.02(±0.67) Acβ	4.66(±0.75) Beα	1.11(±0.18) Cdγ
70–100	26.76(±0.80) Acβ	4.08(±0.70) Beα	0.82(±0.36) Cdγ
	Fraction 2 (F2: Labile organic carbon fraction)		
0–10	13.84(±1.81) Aaγ	4.83(±0.74) Bbδ	2.28(±1.07) Caγ
10–20	12.86(±1.57) Aaγ	6.43(±1.22) Baγ	1.65(±0.73) Cabγ
20–30	5.32(±0.71) Acdγ	5.96(±1.38) Aaγ	1.01(±0.23) Bbcγ
30–50	6.16(±1.49) Acδ	2.86(±0.83) Bcγ	1.06(±0.65) Cbcγ
50–70	4.80(±0.64) Acdγ	1.92(±0.38) Bcβ	1.03(±0.49) Cbcγ
70–100	4.02(±0.89) Adγ	1.86(±0.49) Bcγ	0.68(±0.33) Ccγ
	Fraction 3 (F3: Less labile organic carbon)		
0–10	4.04(±1.13) Bcδ	7.58(±1.43) Aaγ	3.77(±0.79) Baβ
10–20	5.28(±1.54) Abδ	3.59(±1.22) Bbδ	1.36(±0.77) Ccγ
20–30	6.07(±0.33) Abγ	3.08(±1.28) Bbcδ	1.64(±0.60) Cbcγ
30–50	9.04(±0.67) Aaγ	2.84(±0.82) Bbcγ	2.80(±1.29) Babβ
50–70	4.15(±0.69) Acγ	1.85(±0.68) Bcβ	2.77(±0.95) Babβ
70–100	4.09(±0.71) Acγ	1.95(±0.80) Bcγ	2.42(±1.00) Bbcβ
	Fraction 4 (F4: Recalcitrant organic carbon)		
0–10	52.54(±2.42) Abcα	51.45(±1.67) Aaα	10.16(±1.44) Bcα
10–20	53.41(±3.59) Abα	43.46(±1.06) Bbα	12.28(±0.88) Cabα
20–30	65.66(±2.43) Aaα	50.68(±2.37) Baα	12.88(±1.13) Caα
30–50	53.79(±2.27) Abα	10.37(±1.51) Bcα	11.14(±1.69) Bbcα
50–70	50.02(±2.03) Abcα	4.81(±0.97) Cdα	10.33(±1.90) Bcα
70–100	40.02(±1.50) Adα	3.06(±0.63) Ceβ	6.89(±1.03) Bdα

3.3. Relationship of SOC with Four SOC Fractions

Considering the four fractions, the regression coefficient between the SOC content and F4 (R = 0.96, t = 24.49) was higher than that for F1 (R = 0.93, t = 16.56), F2 (R = 0.72, t = 8.32), and F3 (R = 0.38, t = 4.38) (Figure 4). In addition, based on the Pearson correlation analysis (Table 3), the SOC in the Bayinbuluk alpine wetland was significantly positively correlated with the four OC fractions. Of these four fractions, only F2 and F3 presented no significant difference.

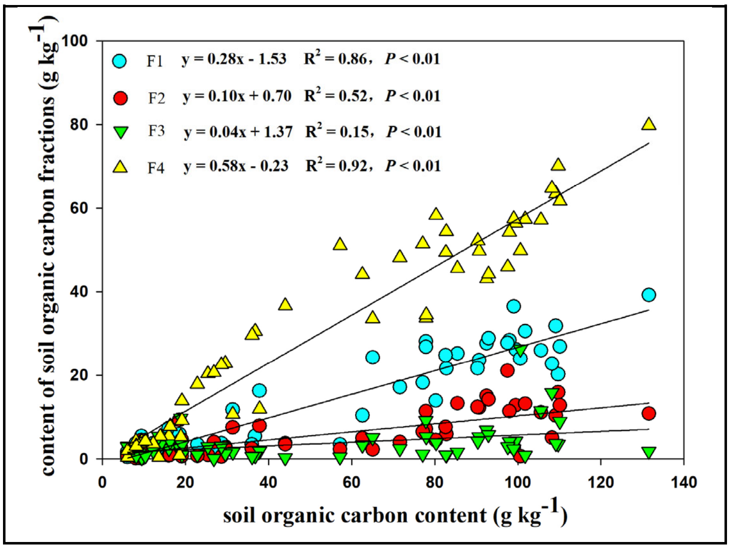

Figure 4. Linear relationship between SOC and SOC fractions under different levels of degradation.

Table 3. Pearson correlation analysis between SOC with SOC fractions. Note: * and ** denote 95% and 99% significance levels, respectively.

	SOC	Fraction 1	Fraction 2	Fraction 3
Fraction 1	0.959 **	-	-	-
Fraction 2	0.642 **	0.518 **	-	-
Fraction 3	0.609 **	0.529 *	0.223	-
Fraction 4	0.992 **	0.938 **	0.596 **	0.592 **

3.4. SOC Stability and CMI Under Different Degradation Areas

Degradation had a great influence on the stability of the CMI (Figure 5a) and SOC (Figure 5b). The CMI at 10–20 cm and 30–50 cm was significantly higher than that in the SD area ($p < 0.05$). At 50–100 cm, there was no significant difference in the CMI between the ND and HD areas ($p > 0.05$). On average, the CMI of the SD and HD areas at the depth of 0–100 cm was 50.35 and 56.15, respectively. The lability of soil organic carbon at depths of 0–10 cm and 50–70 cm for different degradation levels significantly differed ($p < 0.05$).

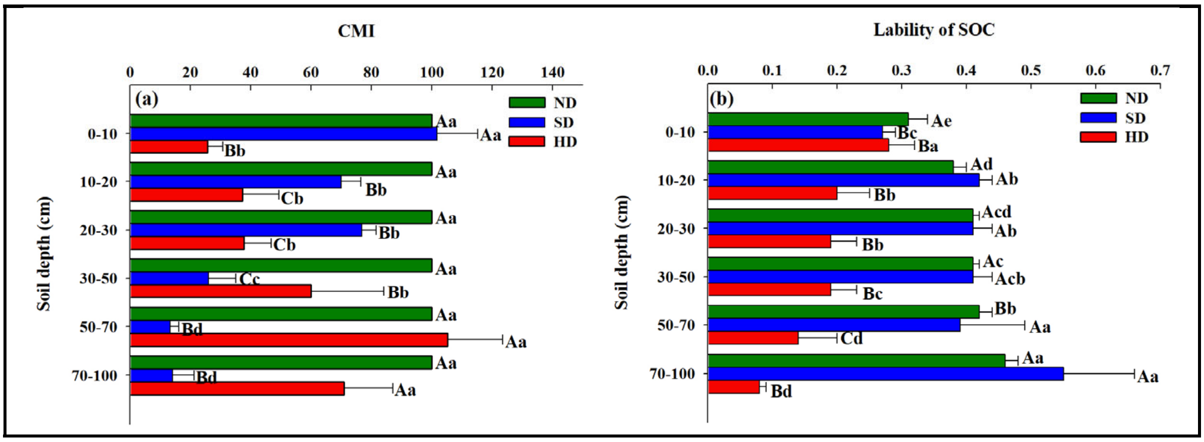

Figure 5. CMI (**a**) and stability of SOC (**b**) at six depths of soil under different degradation levels. Different uppercase letters in the rows (degradation degree), lowercase letters in the columns (soil depth).

4. Discussion

4.1. Changing Trend and Driving Factors of SOC Under Wetland Degradation

Vegetation litter, root exudates, and microbial residues are the main sources of SOC. The amount and quality of organic matter input into the soil through litter from different vegetation communities differ, which affects the soil carbon pool [34]. The SOC content has a strong depth dependence under different degrees of degradation, and the SOC content at a depth of 0–30 cm is higher than that at a depth of 30–100 cm (Figure 3). This is because the dominant plant community in the ND area is *Carex*, and its root biomass and litter input are significantly higher than *Leymus* species in the HD area, resulting in higher organic carbon accumulation in the surface soil [30]. The degradation of wetland significantly affects the vertical distribution of SOC, and the SOC content at different depths decreases significantly with the degradation of wetland (Figure 3). Related research results show that, compared with the original swamp wetland, the total organic carbon content of slightly and severely degraded soil in the Zoige alpine wetland (Qinghai–Tibet Plateau) was decreased by 34.13% and 61.41%, respectively [35,36]. This shows that with a decrease in the primary productivity of vegetation, the SOC content decreased significantly [37]. As such, Table 1 shows that degradation leads to a decrease in vegetation coverage and aboveground biomass, which directly weakens the input of organic carbon [15]. Grazing disturbance and soil erosion will also aggravate the degradation of wetlands. In Table 1, the grazing intensity in the HD area increased to 6.4 times that in the ND area, which directly led to a 70% decrease in vegetation coverage. In addition, grazing affects surface soil, gas emission and water conduction, increases the area of exposed soil and the intensity of wind erosion and rain erosion, and promotes SOC loss [26]. Degradation significantly impacts soil moisture and microbial activities [9]. Degradation leads to a decline in the soil water content, and the evaporation of soil water is increased to enhance oxygen penetration, thus accelerating the mineralization rate of organic carbon by microorganisms [35]. To sum up, degradation leads to the vertical redistribution of SOC by reducing the vegetation carbon input (e.g., roots and litter) and increasing the carbon output (e.g., erosion and mineralization), thereby exacerbating deep carbon loss [38,39].

4.2. Decoupling of SOC Composition and Stability

Similar to the SOC content, the four SOC fractions at 0–100 cm in the ND area were significantly higher than those in the SD and HD areas (Table 2). This may be related to the aboveground vegetation and the supply of root biomass [15,19,40], as an increase in aboveground vegetation biomass leads to increased litter input into the soil, which will directly increase the input of soil carbon sources, promote the turnover of the soil carbon pool, and increase the quantity of active organic carbon coming from plant residues and leaves [10,41]. In addition, in the process of wetland degradation, plant growth is sparse and the amount of litter returned is low, which will weaken microbial activities and slow down the release of active OC [10]. Compared with the SD and HD areas, the four fractions in the ND area changed little with the soil layers, indicating that the interference in the ND area is low. However, the content of the F4 component in the 0–100 cm soil layers in the SD and HD areas varies greatly with the depth of the soil layer, which indicates that recalcitrant carbon will also be affected by wetland degradation. In our research, F1 in the range of 0–100 cm accounts for 31% of SOC, which is lower than that of oxidizable organic carbon in the soil of Songnen Plain (the proportion of F1 in SOC is more than 40%) [15], but higher than that of F1 in the soil of the western Ganges Plain, India (24.8–28.9%) [42]. The differences between these results are mainly related to differences in climate, management measures, and soil properties [43,44]. In this study, the contents of F1 and F4 at a depth of 0–100 cm in the ND area were significantly higher than those in the two other areas, which may be due to unreasonable grazing having reduced the protection of soil aggregates in soil C, ultimately reducing the stability of carbon [42,45]. In addition, the decline of soil moisture in degraded wetlands increased the oxygen content, promoted the activity of microorganisms, and preferentially decomposed F1 components, resulting in a sharp decline in the activated carbon bank (Table 2, Figure 5b).

In addition, due to the close correlation between SOC and its fractions, the linear relationship between SOC and its fractions is significant ($p < 0.001$; Figure 4). Based on Yu et al. [30], Chan et al. [33] referred to the OC oxidized by 6 mol/L H_2SO_4 as a "very labile organic carbon component". The determination methods used in this study were similar to those of Barreto et al. [19], Datta et al. [41], Yu et al. [15], and Liu et al. [31]. Consistent with their research results, the proportion of the F1 component in total organic carbon in this study was higher than the normal value recognized by researchers (<20%). At the same time, Yu et al. [30] pointed out that, when using the improved Walkley and Black (1989) [32] method, the organic carbon oxidized with low concentration of H_2SO_4 was less than that oxidized with a high concentration, and its content was very close to the normal value. Hence, when the improved determination method is adopted in future research, we will also control the concentration of H_2SO_4 below 6.00 N.

CMI can reflect the differences in wetland soil quality under different degradation conditions from the perspective of the organic carbon pool. Through calculating the CMI of the F1 component, it was found that the CMI of the 0–30 cm soil in the SD area and 30–100 cm soil in the HD area was higher. This indicates that degradation had a negative effect on the quantity and quality of low-level soil carbon in the SD area and surface soil carbon in the HD area [15]. The lability of SOC can determine the OC stability and C loss [37]. Here, at 0–100 cm, the SOC lability in the ND and SD regions was higher than that in the HD areas (Figure 5b). The higher stability of SOC indicates that the soil organic carbon in this area is more stable than that in other areas [16]. Our previous research indicates that wetland succession leads to a sharp decline in soil aggregates, thereby reducing the protection of SOC [46]. In wetland ecosystems with a high water content, the reduction in water content accelerates the rate of microbial decomposition in SOC and decreases the stability of SOC [47,48].

5. Conclusions

Our results show that wetland degradation significantly reduced the contents of SOC and its components during degradation from ND to HD in the Bayinbuluk alpine wetland. Significant linear relationships were observed between the four organic carbon components and the total organic carbon content, indicating that the total organic carbon is the main determinant of the oxidizable organic carbon components. The regression coefficient of the F4 components was rather high, indicating that the SOC in the study area was dominated by a recalcitrant carbon fraction. Compared with the F1, F2 and F3 components, the F4 components vary greatly between different areas. Our results show that the recalcitrant components may also be affected by wetland degradation. Wetland degradation had a significant effect on the CMI and lability of SOC, indicating that wetland degradation changed the stability of SOC and reduced the soil quality in the Bayinbuluk wetlands.

Author Contributions: Data curation, M.A.; Investigation, M.A., M.C., Y.T., Y.H. (Yunpeng Hu) and Y.H. (Yang Hu); Methodology, M.A., Y.T. and D.H.; Project administration, J.Z., Z.Y. and H.J.; Resources, J.Z. and H.J.; Supervision, H.J.; Validation, D.H. and Y.H. (Yang Hu); Writing—original draft, M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (No.31560171), and Natural Science Foundation of Xinjiang Uygur Autonomous Region (2022D01A192).

Data Availability Statement: The original contributions presented in this study are included in the article; further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wu, Y.; Gao, W.; Zou, Y.; Dong, H.; Yu, F.; Wang, H.; Zong, C. Effects of Land Use Conversion on the Soil Microbial Community Composition and Functionality in the Urban Wetlands of North-Eastern China. *Forests* **2022**, *13*, 1148. [CrossRef]
2. Khaledian, Y.; Kiani, F.; Ebrahimi, S.; Brevik, E.; Aitkenhead-Peterson, J. Assessment and monitoring of soil degradation during land use change using multivariate analysis. *Land Degrad. Dev.* **2017**, *28*, 128–141. [CrossRef]
3. Wang, Z.; Yang, Z.; Shi, H.; Han, F.; Qin, L.; Qi, J.; Lu, Y. Ecosystem Health Assessment of World Natural Heritage Sites Based on Remote Sensing and Field Sampling Verification: Bayanbulak as Case Study. *Sustainability* **2020**, *12*, 2160. [CrossRef]
4. Zhao, J.; Deng, C.; Li, W.; Zhao, J.; Gong, Y.; Li, K. Evaluation of the degree of degradation of Xinjiang Tianshan Bayinbuluk grassland in 35 years. *Arid Zone Res.* **2023**, *40*, 636–646. [CrossRef]
5. Wu, J.; Wang, H.; Li, G.; Wu, J.; Ma, W. Vertical and seasonal changes in soil carbon pools to vegetation degradation in a wet meadow on the Qinghai-Tibet Plateau. *Sci. Rep.* **2021**, *11*, 12268. [CrossRef]
6. Amthor, J.; Dale, V.; Edwards, N.; Garten, C.; Gunderson, C.; Hanson, P.; Huston, M.; King, A.; Luxmoore, R.; McLaughlin, S.; et al. Terrestrial ecosystem responses to global change: A research strategy. *ORNL Tech. Memo.* **1998**, *27*, 37.
7. Lal, R. Soil carbon sequestration impacts on global climate change and food security. *Science* **2004**, *304*, 1623–1627. [CrossRef]
8. Yu, H.; Zha, T.; Zhang, X.; Ma, L. Vertical distribution and influencing factors of soil organic carbon in the Loess Plateau, China. *Sci. Total Environ.* **2019**, *693*, 133632. [CrossRef]

9. Abulaizi, M.; Chen, M.; Yang, Z.; Hu, Y.; Zhu, X.; Jia, H. Response of soil bacterial community to alpine wetland degradation in arid Central Asia. *Front. Plant Sci.* **2023**, *13*, 990597. [CrossRef]
10. Huo, L.; Chen, Z.; Zou, Y.; Lu, X.; Guo, J.; Tang, X. Effect of Zoige alpine wetland degradation on the density and fractions of soil organic carbon. *Ecol. Eng.* **2013**, *51*, 287–295. [CrossRef]
11. Jiang, X.; Xu, D.; Rong, J.; Ai, X.; Ai, S.; Su, X.; Sheng, M.; Yang, S.; Zhang, J.; Ai, Y. Landslide and aspect effects on artificial soil organic carbon fractions and the carbon pool management index on road-cut slopes in an alpine region—ScienceDirect. *Catena* **2021**, *199*, 105094. [CrossRef]
12. Bationo, A.; Buerkert, A. Soil organic carbon management for sustainable land use in Sudano-Sahelian west Africa. *Nutr. Cycl. Agroecosys.* **2001**, *61*, 131–142. [CrossRef]
13. Alhassan, A.M.; Ma, W.; Li, G.; Jiang, Z.; Wu, J.; Chen, G. Response of soil organic carbon to vegetation degradation along a moisture gradient in a wet meadow on the Qinghai-Tibet Plateau. *Ecol. Evol.* **2018**, *8*, 11999–12010. [CrossRef] [PubMed]
14. Gabarrón-Galeote, M.; Trigalet, S.; Wesemael, B. Effect of land abandonment on soil organic carbon fractions along a Mediterranean precipitation gradient. *Geoderma* **2015**, *249*, 69–78. [CrossRef]
15. Yu, P.; Han, K.; Li, Q.; Zhou, D. Soil organic carbon fractions are affected by different land uses in an agro-pastoral transitional zone in Northeastern China. *Ecol. Indic.* **2017**, *73*, 331–337. [CrossRef]
16. Luo, Y.; Li, Y.; Liu, S.; Yu, P. Effects of vegetation succession on soil organic carbon fractions and stability in a karst valley area, Southwest China. *Environ. Monit. Assess.* **2022**, *194*, 562. [CrossRef]
17. Lorenz, K.; Lal, R.; Ehlers, K. Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations' Sustainable Development Goals. *Land Degrad. Dev.* **2019**, *30*, 824–838. [CrossRef]
18. Soucémarianadin, L.; Cécillon, L.; Guenet, B.; Chenu, C.; Baudin, F.; Nicolas, M.; Girardin, C.; Barré, P. Environmental factors controlling soil organic carbon stability in French forest soils. *Plant Soil* **2018**, *426*, 267–286. [CrossRef]
19. Barreto, P.; Gama-Rodrigues, E.; Gama-Rodrigues, A.; Fontes, A.; Polidoro, J.; Moço, M.; Machado, R.; Baligar, V. Distribution of oxidizable organic C fractions in soils under cacao agroforestry systems in Southern Bahia, Brazil. *Agroforest. Syst.* **2011**, *81*, 213–220. [CrossRef]
20. Wang, G.; Li, Y.; Wang, Y.; Wu, Q. Effects of permafrost thawing on vegetation and soil carbon pool losses on the Qinghai-Tibet Plateau, China. *Geoderma* **2008**, *143*, 143–152. [CrossRef]
21. Ma, H.; Li, Z.; Ma, X.; Gong, L. Characteristics and driving factors of soil organic carbon fractions under different vegetation types of the mid-northern piedmont of the Tianshan Mountains, Xinjiang. *Ecol. Environ. Sci.* **2022**, *31*, 1124–1131. [CrossRef]
22. Ye, X.; Meng, Y.; Xu, L.; Xu, C. Net primary productivity dynamics and associated hydrological driving factors in the floodplain wetland of China's largest freshwater lake. *Sci. Total Environ.* **2019**, *659*, 302–313. [CrossRef] [PubMed]
23. Shen, G.; Yang, X.; Jin, Y.; Xu, B.; Zhou, Q. Remote sensing and evaluation of the wetland ecological degradation process of the Zoige Plateau Wetland in China. *Ecol. Indic.* **2019**, *104*, 48–58. [CrossRef]
24. Jiang, T.; Pan, J.; Pu, X.; Wang, J.; Pan, J. Current status of coastal wetlands in China: Degradation, restoration, and future management. *Estuar. Coastal Shelf. Sci.* **2015**, *164*, 265–275. [CrossRef]
25. Ise, T.; Dunn, A.; Wofsy, S.; Moorcroft, P. High sensitivity of peat decomposition to climate change through water-table feedback. *Nat. Geosci.* **2008**, *1*, 763–766. [CrossRef]
26. Chivers, M.; Turetsky, M.; Waddington, J.; Hardenet, J.; McGuire, A. Effects of Experimental Water Table and Temperature Manipulations on Ecosystem CO_2 Fluxes in an Alaskan Rich Fen. *Ecosystems* **2009**, *1122*, 1329–1342. [CrossRef]
27. Li, Q.; Yu, P.; Li, G.; Zhou, D.; Chen, X. Overlooking soil erosion induces underestimation of the soil C loss in degraded land. *Quatern. Int.* **2014**, *349*, 287–290. [CrossRef]
28. Lorenz, K.; Lal, R. *Carbon Sequestration in Forest Ecosystems*; Springer: Dordrecht, The Netherlands, 2010. [CrossRef]
29. Liu, X.; Chen, D.; Yang, T.; Huang, F.; Fu, S.; Li, L. Changes in soil labile and recalcitrant carbon pools after land-use change in a semi-arid agro-pastoral ecotone in Central Asia. *Ecol. Indic.* **2020**, *110*, 105925. [CrossRef]
30. Yu, P.; Li, Y.; Liu, S.; Ding, Z.; Zhang, A.; Tang, X. The quantity and stability of soil organic carbon following vegetation degradation in a salt-affected region of Northeastern China. *Catena* **2022**, *211*, 105984. [CrossRef]
31. Liu, H.; Zhang, J.; Ai, Z.; Wu, Y.; Xu, H.; Li, Q.; Xue, S.; Liu, G. 16-Year fertilization changes the dynamics of soil oxidizable organic carbon fractions and the stability of soil organic carbon in soybean-corn agroecosystem. *Agric. Ecosyst. Environ.* **2018**, *265*, 320–330. [CrossRef]
32. Walkley, A.; Black, I. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–38. [CrossRef]
33. Chan, K.; Oates, B. Oxidizible organic carbon fractions and soil quality changes in an oxic paleustalf under different pasture leys. *Soil Sci.* **2001**, *166*, 61–67. [CrossRef]
34. Wu, G.; Zhang, M.; Liu, Y.; López-Vicente, M. Litter cover promotes biocrust decomposition and surface soil functions in sandy ecosystem. *Geoderma* **2020**, *374*, 114429. [CrossRef]

35. Pu, Y.; Chu, Y.; Zhang, S.; Wang, G.; Hu, S.; Xu, X.; Xiang, S.; Li, T.; Jia, Y. Response of the Organic Carbon Fractions and Stability of Soil to Alpine Marsh Degradation in Zoige, East Qinghai-Tibet Plateau. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 2145–2155. [CrossRef]
36. Azam, A.; Akhtar, M.; Rukh, S.; Mehmood, A.; Imran, M.; Khan, A.; Qayyum, A.; Ahmad, W.; Gurmani, A. Changes in soil organic carbon fractions across a loess Toposequence. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 1193–1202. [CrossRef]
37. Wang, Q.; Wang, Y.; Wang, Q.; Liu, J. Impacts of 9 years of a new conservational agricultural management on soil organic carbon fractions. *Soil Till. Res.* **2014**, *143*, 1–6. [CrossRef]
38. Sprunger, C.; Robertson, G. Early accumulation of active fraction soil carbon in newly established cellulosic biofuel systems. *Geoderma* **2018**, *318*, 42–51. [CrossRef]
39. Yuan, Z.; Jiang, X.; Liu, G.; Jin, H.; Chen, J.; Wu, Q. Responses of soil organic carbon and nutrient stocks to human-induced grassland degradation in a Tibetan alpine meadow. *Catena* **2019**, *178*, 40–48. [CrossRef]
40. Lehmann, J.; Kleber, M. The contentious nature of soil organic matter. *Nature* **2015**, *528*, 60–68. [CrossRef]
41. Datta, A.; Basak, N.; Chaudhari, S.; Sharma, D. Soil properties and organic carbon distribution under different land uses in reclaimed sodic soils of North-West India. *Geoderma Reg.* **2015**, *4*, 134–146. [CrossRef]
42. Wang, Q.; Zhang, L.; Li, L.; Bai, Y.; Gao, J.; Han, X. Changes in carbon and nitrogen of chernozem soil along a cultivation chronosequence in a semi-arid grassland. *Eur. J. Soil Sci.* **2009**, *60*, 916–923. [CrossRef]
43. Bhattacharyya, R.; Das, T.; Sudhishri, S.; Sharmad, A.; Bhatiad, A.; Geeta, S. Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains. *Eur. J. Agron.* **2015**, *70*, 11–21. [CrossRef]
44. Jackson, R.; Banner, J.; Jobbagy, E.; Pockman, W.; Wall, D. Ecosystem carbon loss with woody plant invasion of grassland. *Nature* **2022**, *418*, 623–626. [CrossRef] [PubMed]
45. Prasad, J.V.N.S.; Rao, C.S.; Srinivas, K.; Jyothi, C.N.; Venkateswarlu, B.; Ramachandrappa, B.K.; Dhanapal, G.N.; Ravichandra, K.; Mishra, P.K. Effect of ten years of reduced tillage and recycling of organic matter on crop yield, soil organic carbon and its fractions in alfisols of semi arid tropics of southern Inida. *Soil. Till Res.* **2016**, *156*, 131–139. [CrossRef]
46. Liusui, Y.; Zhu, X.; Li, D.; Yan, C.; Sun, T.; Jia, H.; Zhao, X. Soil aggregate and intra-aggregate carbon fractions associated with vegetation succession in an alpine wetland of Northwest China. *Catena* **2019**, *181*, 104107. [CrossRef]
47. Hu, Y.; Cong, M.; Chen, M.; Abulaizi, M.; Yu, G.; Yang, Z.; Zhu, X.; Jia, H. Soil bacteria mediate organic carbon stability during alpine wetland biogeomorphic succession in the arid region of Central Asia. *Plant Soil* **2023**, *497*, 429–447. [CrossRef]
48. Zhao, Y.; Wang, X.; Ou, Y.; Jia, H.; Li, J.; Shi, C.; Liu, Y. Variations in soil δ13C with alpine meadow degradation on the eastern Qinghai–Tibet plateau. *Geoderma* **2019**, *338*, 178–186. [CrossRef]