Effects of Flood Inundation on Soil Organic Carbon and Labile Fractions in Riparian Populus euphratica Forests in the Middle Reaches of the Tarim River (Postprint)

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Abstract

Ecological water conveyance in the Tarim River has increased flood overflow intensity along both banks of the basin, thereby exerting important influences on the carbon cycle of the riparian Populus euphratica forest ecosystem. Taking the Populus euphratica forests in the periodic flood overflow zone of the middle Tarim River as the research object, we measured and analyzed the variation characteristics of soil organic carbon and active component contents in the 1 m soil profile during different stages of flood overflow in the riparian Populus euphratica forests: pre-overflow (W1), 4th day of overflow (W2), 17th day of overflow (W3), and post-water recession (W4). The results showed that: (1) SOC (soil organic carbon) content was higher before overflow than after overflow; flood overflow had a more significant effect on SOC content in the 0–20 cm soil layer than in the 20–100 cm soil layer; within the same stage, SOC content showed a decreasing trend with increasing soil depth. (2) Soil DOC (dissolved organic carbon) and MBC (microbial biomass carbon) contents in the 0–10 cm and 40–100 cm soil layers were significantly higher on the 4th day of overflow than before overflow, but gradually decreased with prolonged overflow duration, with significant differences among stages ($P<0.05$); DOC/SOC and MBC/SOC ratios in the same soil layer showed significant differences with increasing overflow duration ($P<0.05$). (3) EOC (easily oxidizable organic carbon) content in the 0–10 cm soil layer was higher before overflow than after overflow, while in other soil layers, EOC content was higher during the overflow period than before overflow and after water recession; EOC/SOC ratios in the 0–10 cm and 20–60 cm soil layers showed significant differences among different overflow stages ($P<0.05$). (4) SOC and DOC contents showed extremely significant positive correlations from pre-overflow to the 17th day of overflow ($r>0.69$, $n=15$), EOC and DOC showed a significant positive correlation after water recession (r=0.54, n=15), and SOC and DOC contents before overflow showed significant correlations with contents at various stages after overflow. In summary, the flood overflow process in the middle Tarim River had significant effects on the distribution of SOC and its active components in riparian Populus euphratica forests, and the sensitive soil layers differed among components: SOC was most significantly affected in the 0–20 cm soil layer, DOC and MBC were most significantly affected in the 0–10 cm and 40–100 cm soil layers, and EOC was most significantly affected in the 20–60 cm soil layer, with its variation pattern exhibiting dual characteristics of both forest and wetland.

Full Text

Effects of Flood Overflow on Soil Organic Carbon and Active Components in Riparian Populus euphratica Forests in the Middle Reaches of the Tarim River

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Abstract: Ecological water conveyance in the Tarim River basin has increased flood overflow intensity along both banks, significantly impacting the carbon cycle of riparian Populus euphratica forest ecosystems. This study examined a P. euphratica forest in the middle reaches of the Tarim River subject to periodic flooding, measuring and analyzing changes in soil organic carbon and active components across four distinct stages: pre-flood (W1), day 4 of flooding (W2), day 17 of flooding (W3), and post-flood (W4). Results demonstrated that soil organic carbon (SOC) content was higher before and after flooding compared to during the flood period. The effect of flood overflow on SOC content was more pronounced in the 0–20 cm soil layer than in the 20–100 cm layer. Within each stage, SOC content decreased with increasing soil depth. Dissolved organic carbon (DOC) and microbial biomass carbon (MBC) contents in the 0–10 cm and 40–100 cm layers increased significantly on day 4 of flooding compared to pre-flood levels, but gradually declined with prolonged flooding duration, with significant differences among stages ($P < 0.05$). The DOC/SOC and MBC/SOC ratios in the same soil layer showed significant differences as flooding time extended ($P < 0.05$). Easily oxidizable organic carbon (EOC) content in the 0–10 cm layer was higher before flooding than after, while other layers showed higher EOC during flooding than before or after. The EOC/SOC ratio differed significantly among flood stages in the 0–10 cm and 20–60 cm layers ($P < 0.05$). SOC content showed a significantly positive correlation with DOC content from pre-flood to day 17 of flooding ($r > 0.69$, $n = 15$), and EOC content was significantly positively correlated with DOC content after water recession ($r = 0.54$, $n = 15$). SOC content before flooding was significantly correlated with SOC content at all post-flood stages. In summary, the flooding process in the middle reaches of the Tarim River significantly affected the distribution of SOC and its active components in riparian P. euphratica forests, with different sensitive soil layers for each component. The 0–20 cm layer was most sensitive for SOC, the 0–10 cm layer for DOC and MBC, and the 20–60 cm layer for EOC. The observed patterns exhibited dual characteristics of both forest and wetland ecosystems.

Keywords: riparian Populus euphratica forest; flood overflow; soil organic carbon; active components; distribution characteristics; Tarim River

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1 Study Area Overview

The study area is located in the Tarim River Populus euphratica Nature Reserve in Luntai County, Lunnan Town, in the middle reaches of the Tarim River (84°15 –85°30 E, 40°55 –41°15 N). Situated on the northern edge of the Taklamakan Desert, the reserve covers a total area of 3954 km^2 with flat terrain at an elevation of 800–940 m. The climate is temperate continental desert, with an average annual temperature of 9.7–10.8 °C, annual sunshine duration of 2925 h, average annual precipitation of 45.2 mm concentrated in June–August, and potential evaporation of 1887–2910 mm. Dry hot winds and strong winds are frequent. The soil is primarily Populus euphratica forest soil. Vegetation consists mainly of desert riparian forests and halophytic meadows, including Populus euphratica, Tamarix ramosissima, Halimodendron halodendron, Reaumuria songonica, Phragmites communis, Kobresia myosuroides, and Achnatherum splendens, with P. euphratica and T. ramosissima as the constructive species.

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2 Research Methods

2.1 Sample Plot Establishment

A typical permanent monitoring plot was established in the flood overflow area of the riparian P. euphratica forest at the Tarim River Populus euphratica Ecosystem Research Station of the National Forestry and Grassland Administration. Located in a national key public welfare forest area at 84°17 40 E, 41°13 36 N, the 100 m × 100 m plot featured a steel-wood observation platform built perpendicular to the north side flood control dike of the Tarim River. The platform consisted of three main channels at 3.0 m above ground and five branch channels at 5.5 m above ground, providing access to different sampling points with a total channel length of 200 m. A 2.5 m high mesh fence was installed around the plot to prevent human disturbance and wildlife entry. The forest canopy density was 0.15, with an average diameter at breast height of 13.2 cm and average crown width of 2.8 m × 3.0 m. The plot encompassed all three vegetation types (arboreal, shrub, and herbaceous) present in the study area, with soil classified as Populus euphratica forest soil. The flood arrived on June 15 and receded on August 23, reaching a maximum depth of 1.8 m.

2.2 Sample Collection

Soil samples were collected at four stages: pre-flood (W1), day 4 of flooding (W2), day 17 of flooding (W3), and post-flood (W4). Using the observation platform, samples were collected with a specialized wetland soil auger. Three 30 m × 30 m quadrats were arranged in a “品” pattern within the plot, with three sampling points established in each quadrat. Soil samples were collected from six layers: 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm. Soils from the same layer in each quadrat were mixed to form one composite sample of approximately 1.0 kg, yielding 18 samples per stage. Samples were immediately divided into two portions: one stored in liquid nitrogen and then kept at -80 °C for MBC determination, and the other air-dried and sieved for SOC and other measurements.

2.3 Measurement Indicators

Dissolved organic carbon was determined using the cold water extraction method, mixing soil with distilled water at a 1:2.5 ratio, shaking for 10 minutes at 4000 $\mathrm{r \cdot min^{-1}}$, filtering through a 0.45 m membrane, and measuring organic carbon in the filtrate. Easily oxidizable organic carbon was measured using the potassium dichromate oxidation method, placing 15–30 mg of soil containing organic carbon in a plastic bottle with 100 mL of 333 $\mathrm{mmol \cdot L^{-1}}$ $KMnO_4$, sealing, rotating at 25 rpm for 30 minutes, filtering the supernatant, diluting 1:250 with deionized water, and measuring absorbance at 565 nm to calculate EOC content from $KMnO_4$ consumption. Microbial biomass carbon was determined using the chloroform fumigation-K_2SO_4 extraction method, fumigating fresh soil samples with chloroform vapor, extracting with 0.5 $\mathrm{mol \cdot L^{-1}}$ K_2SO_4, and measuring organic carbon in the extract with a conversion coefficient of 0.45. Soil organic carbon was measured using the potassium dichromate external heating method.

2.4 Data Processing

Data were processed using Microsoft Excel 2010. One-way ANOVA in SPSS 19.0 analyzed differences in SOC and active components across flood stages and soil layers, with least significant difference (LSD) for multiple comparisons. Pearson correlation coefficients characterized relationships between SOC and active components. Origin 2021 software generated figures.

3 Results

3.1 Soil Organic Carbon Distribution Characteristics

During the flood overflow process, SOC content in the 0–100 cm profile ranged from 2.57 to 9.35 $g \cdot kg^{-1}$, with all layers affected to varying degrees, most notably in the 0–20 cm layer. SOC content decreased with soil depth before flooding and after water recession, except during certain flood stages where the 0–10 cm layer was significantly higher than other layers ($P < 0.05$). In the 0–10 cm layer, SOC content was highest before flooding (9.35 ± 1.10 $g \cdot kg^{-1}$), showing an irregular “V-shaped” pattern during flooding, with significantly higher content before flooding than on day 4 ($P < 0.05$). The 10–20 cm layer exhibited a wave-shaped pattern, peaking on day 17. The 20–60 cm layer showed similar variation to the 0–10 cm layer, gradually increasing and peaking on day 17. In the 60–100 cm layer, SOC content was significantly higher before and after flooding than on day 17 ($P < 0.05$), with no significant differences among flood stages in deeper soils (40–100 cm) .

3.2.1 Soil MBC Distribution Characteristics

MBC content ranged from 20.67 to 769.33 $mg \cdot kg^{-1}$ across the soil profile, showing irregular “V-shaped” variation with depth. High values appeared in different layers at different stages, with significant differences among layers ($P < 0.05$). MBC content increased significantly as surface water accumulated from none to shallow depths, then decreased as water depth continued to increase. The middle (20–40 cm) and bottom (60–100 cm) layers showed decreasing MBC with prolonged waterlogging. The 0–10 cm layer had significantly higher MBC than other layers on day 4 (367.67 ± 36.34 $mg \cdot kg^{-1}$), day 17 (570.62 ± 65.41 $mg \cdot kg^{-1}$), and post-flood (289.80 ± 36.18 $mg \cdot kg^{-1}$), with significant differences among stages ($P < 0.05$). The MBC/SOC ratio ranged from 1.98% to 27.74%, showing an irregular inverted “V-shaped” pattern in the 0–20 cm layer, decreasing with water depth, while other layers peaked on day 17. The ratio differed significantly among stages in all layers except 10–20 cm ($P < 0.05$), with the highest average ratio on day 17 (19.98%) [Figure 1: see original paper].

3.2.2 Soil EOC Distribution Characteristics

EOC content ranged from 0.20 to 2.54 $g \cdot kg^{-1}$, with minimal vertical variation before flooding and on day 4, averaging around 2.14 $g \cdot kg^{-1}$. EOC content was significantly higher in the 0–10 cm layer than other layers across all stages ($P < 0.05$). As flooding duration extended, EOC content decreased continuously in the 0–10 cm layer but increased in the 20–60 cm layer. The EOC/SOC ratio ranged from 6.25% to 94.66%, showing an irregular inverted “V-shaped” pattern across flood stages, with the highest ratio on day 17. The ratio differed significantly among stages in all layers except 20–40 cm ($P < 0.05$), showing wave-shaped vertical variation [Figure 2: see original paper].

3.2.3 Soil DOC Distribution Characteristics

DOC content ranged from 45.90 to 270.67 $\mathrm{mg \cdot kg^{-1}}$, decreasing with soil depth in all stages except post-flood, where vertical distribution was unclear. The 0–10 cm layer was significantly higher than other layers ($P < 0.05$). Horizontally, DOC content increased slowly as surface water accumulated from none to shallow depths, then decreased rapidly as water depth increased. DOC content differed significantly among flood stages ($P < 0.05$), with average values of 87.33 ± 29.54 $\mathrm{mg \cdot kg^{-1}}$ (W1), 152.22 ± 66.69 $\mathrm{mg \cdot kg^{-1}}$ (W2), 115.65 ± 32.98 $\mathrm{mg \cdot kg^{-1}}$ (W3), and 68.54 ± 32.28 $\mathrm{mg \cdot kg^{-1}}$ (W4). The DOC/SOC ratio ranged from 0.73% to 6.42%, peaking on day 4 (4.71%) and showing similar patterns to MBC/SOC but with different vertical trends. The ratio differed significantly among stages in all layers ($P < 0.05$) [Figure 3: see original paper].

3.3 Correlation between SOC and Active Components

Correlation analysis revealed inconsistent relationships among SOC and active components across flood stages . SOC content was extremely significantly positively correlated with DOC content before flooding and on day 4 ($r = 0.58$, $n = 15$), and significantly positively correlated after flooding ($r = 0.54$, $n = 15$). SOC content before flooding was significantly correlated with SOC content at all post-flood stages.

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4 Discussion

In soils, organic matter enters water bodies as dissolved organic carbon (DOC) and particulate organic carbon, representing an important pathway for soil organic carbon loss. In wetland ecosystems, organic carbon content is higher in moist environments than in flooded environments, indicating that flooding causes substantial soil organic carbon loss through water flow, with the most pronounced effects on surface soils while deep soil organic carbon shows minimal variation along hydrological gradients. This study found that flood overflow in riparian P. euphratica forests caused significant organic carbon loss in surface layers (0–10 cm), while deep soil organic carbon remained stable. Typically, forest soil organic carbon decreases with soil depth, and this pattern was observed in the riparian forest before flooding and after water recession. However, during flooding, surface soil organic matter leaching caused increased organic carbon in deep layers (40–100 cm), demonstrating wetland-like characteristics. Overall, pre-flood SOC content was higher than during flooding because plant litter and residue decomposition represent the primary SOC source. During flooding, surface water prevents direct litter input to soil, resulting in lower SOC content during flood periods compared to before and after.

Soil active organic carbon components are more sensitive to environmental changes than total SOC, serving as important indicators of soil carbon dynamics. In wetland surface soils (0–20 cm), MBC content follows the pattern:

never flooded > flooded then drained > short flooding duration > long flooding duration, showing significant reductions compared to unflooded sites. This study found that surface MBC in the riparian forest decreased significantly with prolonged flooding, particularly in the 0–10 cm layer, consistent with wetland research. Short-term waterlogging promotes microbial utilization of soil carbon and enhances microbial activity, but prolonged flooding limits microbial physiology through oxygen availability, reducing MBC and slowing SOC decomposition. The increase in deep MBC with flooding duration requires further investigation.

DOC represents a directly utilizable carbon source for soil microorganisms, characterized by high mobility and rapid decomposition into CO_2 or loss with water flow. Slow surface runoff insufficiently exports organic carbon, while strong runoff increases losses. Shallow water accumulation increases DOC content, while deeper water decreases it. In this study, riparian forest DOC content increased significantly as surface water accumulated from none to shallow depths, then decreased as water depth increased continuously, consistent with studies on regeneration and plantation forests. With increasing leaching time and intensity, DOC content continued to decline during flooding because standing water prevented effective litter input to soil.

The MBC/SOC ratio (microbial quotient) serves as an effective indicator for evaluating soil processes and health changes, reflecting microbial carbon formation rates and organic carbon pool turnover rates. Higher microbial quotients during short-term flooding indicate greater microbial activity and faster MBC formation, consistent with wetland research. The sensitive soil layers for flood response were 0–10 cm for DOC, 20–60 cm for MBC, and 40–100 cm for EOC, which can serve as indicator layers for studying flood effects on soil carbon.

The proportion of active organic carbon components indicates nutrient cycling rates and SOC activity. Among the active components, EOC represented the largest proportion, with EOC/SOC significantly higher on day 17 than day 4, indicating high organic carbon activity and transformation rates. This aligns with research showing that seasonally flooded and rarely flooded wetland soils have significantly higher EOC/SOC ratios than permanently flooded soils. The decreasing EOC/SOC ratio with prolonged flooding likely results from enhanced reducing conditions that reduce organic matter oxidation. DOC is more easily lost in permanently flooded habitats, resulting in lower DOC/SOC ratios than in seasonally flooded conditions. In this study, DOC/SOC ratios in all layers increased then decreased during flooding, peaking on day 4, with continuous water level fluctuations causing DOC loss.

5 Conclusions

Analysis of soil organic carbon and active component changes during periodic flooding of riparian P. euphratica forests in the middle Tarim River yields the following conclusions:

1. Flood overflow caused significant organic carbon loss in surface layers of riparian P. euphratica forests, with active component contents and their allocation ratios showing initial increases followed by decreases, indicating that short-term flooding promotes SOC decomposition while prolonged flooding enhances SOC stability.
2. The sensitive layers for flood response differed among components: 0–10 cm for DOC, 20–60 cm for MBC, and 40–100 cm for EOC. These layers can serve as indicators for studying flood effects on soil carbon dynamics.
3. SOC content was significantly positively correlated with DOC content throughout the flooding process, indicating that DOC content largely reflects SOC content and that microbial quotient changes during flooding result from water environment effects on microbial communities.

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