

Study on Soil Enzymes of Typical Plant Communities in Ecological Reconstruction Wetland

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Abstract: This study comparatively assessed soil enzyme activities in three constructed plant communities and one natural community in the Chongxi tidal flat wetland of the Yangtze River Estuary. The results demonstrated that rhizosphere soil in *Alnus trabeculosa* plantations exhibited significantly higher alkaline phosphatase, protease, urease, and catalase activities compared to artificial communities dominated by *Phragmites communis*, *Salix matsudana*, and *Taxodium distichum* ($P < 0.01$). Vertical distribution analysis revealed that protease and urease activities markedly decreased with depth (61.93% reduction on average), while catalase activity remained stable. Alkaline phosphatase activity generally declined with depth but displayed a distinct peak at 15–30 cm. Notably, rhizosphere soil enzyme activities were 1.07–2.84 times higher than non-rhizosphere levels. These findings highlight *Alnus trabeculosa* as a keystone species for enhancing soil biogeochemical functions in estuarine wetland restoration.

Keywords: Yangtze River Estuary; Chongxi wetland; Enzyme-driven nutrient cycling; Ecological restoration; Rhizosphere microbiome

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1. Introduction

Estuarine and coastal wetlands are among the most important ecosystems in the world as areas of interaction between land and sea ^[1]. As a typical ecotonal ecosystem between land and water, its unique hydrological conditions and sedimentary environment have shaped a special biogeochemical cycling pattern. Estuarine wetland is an ecosystem that is strongly affected by tidal and runoff hydrodynamics between rivers, marine ecosystems, and terrestrial ecosystems. The interaction between surface river runoff and Marine currents results in unique habitat conditions and ecological functions in estuarine areas, which are characterized by high productivity, diverse biological species, and strong interference by human activities ^[2]. Especially under global climate change, estuarine wetlands show matchless ecological service value in carbon sequestration, coastal protection, and

biodiversity conservation ^[3].

Wetland ecosystem plays an important role in the migration of nutrients, water, and pollutants, and is an important control factor of the global nitrogen, phosphorus, sulfur, and other substances cycle. Soil microorganisms play a vital role in estuarine wetlands, not only capable of decomposing organic matter, but also participating in the biogeochemical cycle of elements ^[4]. The material cycle is an important function of the ecosystem. The interruption of any link in the cycle will affect the function of the ecosystem. Organic material in wetland sediments is converted to inorganic material through biological and chemical decomposition, which in turn provides nutrients for the next cycle. Soil enzymes play a central role in the biogeochemical processes within soil ecosystems, primarily originating from microbial secretions, root exudates, and the decomposition of plant and animal residues. These enzymes regulate nutrient cycling and are sensitive indicators of ecological changes in wetland environments. Key enzymes such as dehydrogenase, urease, and phosphatase function as biocatalysts that accelerate the decomposition of organic matter by lowering the activation energy required for biochemical reactions. Their activity reflects the intensity of nutrient turnover and is widely recognized as a sensitive metric for evaluating soil health and ecosystem functioning.

It is generally believed that the decomposition of soil enzymes is the limiting factor of the decomposition rate of organic matter and plays a pivotal role in the mineralization process of organic matter. Relevant research shows that complex compounds must be decomposed into low molecular weight compounds by soil enzymes. Low molecular weight compounds can rarely be transported into cells for oxidation and use as an energy source or as a building block of the body. The decomposition of soil enzymes is generally regarded as a restrictive step in the whole process of organic matter decomposition, which controls the material circulation of the wetland ecosystem and determines the purification function of the wetland ^[5]. Therefore, the level of soil enzyme activity affects the function of the wetland ecosystem and is often an important indicator of the decomposition cycle of wetland substances. Recent research has shown that the temperature sensitivity (Q10) of enzyme — promoted reactions varies significantly among different wetland types. This is crucial for predicting carbon cycle responses to climate change.

The study of soil enzyme activity is one of the most active frontier disciplines in soil ecology, and has become a hot topic and focus of multi-disciplinary research. Previous studies on soil enzyme activity have primarily concentrated on agricultural and terrestrial forest soils, while research on enzyme dynamics in estuarine tidal flat wetlands remains limited ^[6-8]. There is relatively little research on soil enzyme activity in estuarine tidal flat wetlands with unique locations and special service functions ^[9]. However, studies on soil enzyme activities of *Alnus trabeculosa* and *Taxodium distichum* plantations in estuarine tidal flat wetlands and their comparison with other plant communities have not been reported. Notably, *Alnus trabeculosa*, a nitrogen-fixing tree species, may influence nitrogen-cycling enzyme activity through root nodule bacteria. *Taxodium distichum*, with its flood tolerance, may alter soil redox conditions, thus affecting the enzyme system.

This study investigated the soil enzyme activity in natural and artificial communities at the Chongxi River Estuary tidal flat wetland ecological construction site. The study focused on the profile distribution of enzyme activity under different vegetation types and its coupling with environmental factors. This aims to explore the impacts and mechanisms of introducing *Alnus trabeculosa* and *Taxodium distichum* on soil properties, especially the regulation of key carbon, nitrogen, and phosphorus cycling enzymes by afforestation. Our findings will offer practical data for species management in wetland restoration and ecological reconstruction of estuarine tidal flats.

2. Materials and methods

2.1. Study area

The study site is located in the Chongming Xisha Wetland Ecological Restoration Experimental Base (E121°12'~16', N31°42'~44') at the west end of Chongming Island in the Yangtze River Estuary (**Figure 1**). This region belongs to the Southeast Asian monsoon climate, with an average annual temperature of 15.5°C, average annual water temperature of 17.5°C, salinity of 0–1‰, and mainly freshwater. The tidal property belongs to the irregular semi-diurnal shallow sea tide, with an annual mean range of 2.20~4.0 m. The tidal flat substrate is soft facies sediment, mostly gray and grayish brown clayey silt. Since a small embankment was built for extensive fish culture in Chongxi Wetland in the 1990s, it still has a high elevation after the removal of the embankment. The average elevation of the high water zone is above 3.5 m, especially in the place near the levee, which is mostly between 4–5 m. In addition, due to its special geographical location, the salinity of Chongxi wetland is below 1‰, which provides high feasibility for the construction of tidal freshwater forested wetlands.

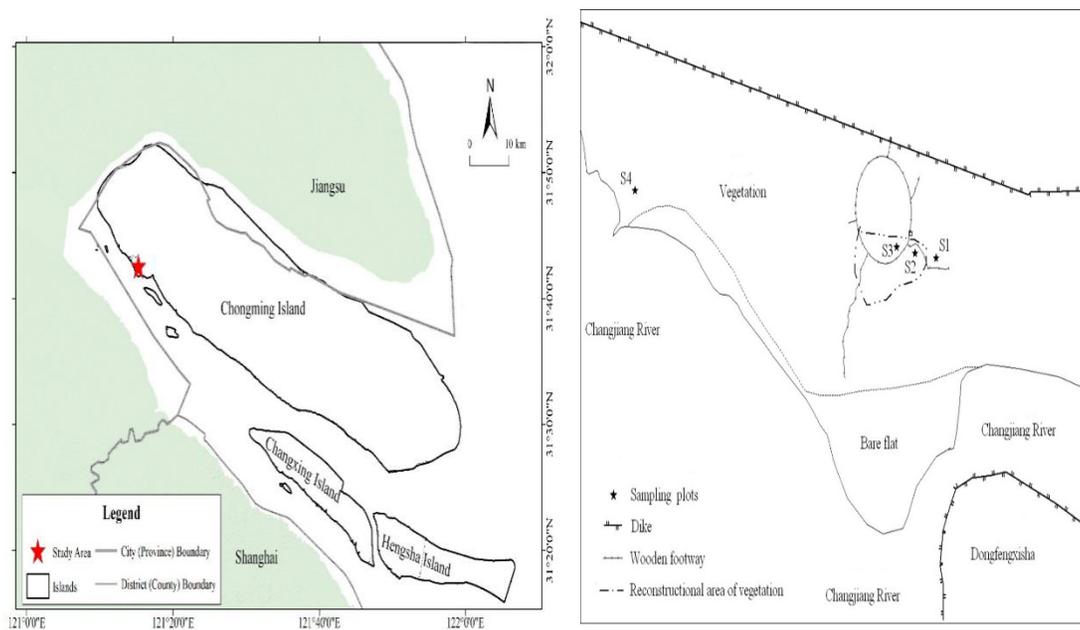


Figure 1. Chongxi wetland ecological engineering region (black area, 3.5ha)

The vegetation of Chongxi Wetland mainly includes tidal flat salt marsh plants and an artificial forest. The dominant species of the former are *Phragmites communis*, while the main tree species of the latter are *Salix matsudana*, etc. The wetland has the problems of single species, single structure, poor landscape effect, and weak biodiversity conservation function. In January 2006, combined with forest phase transformation and landscape design, ecological restoration and reconstruction of Chongxi wetland were carried out. Wet woody plants such as *Alnus trabeculasa* and *Taxodium distichum* were introduced into the original reed community to form a patch community and build a unique tidal freshwater forest wetland in the high tide area. The survival rate of the introduced *Alnus trabeculasa* was 91.0%, and that of *Taxodium distichum* was 100%.

2.2. Sample site selection and survey

Four communities of *Phragmites communis* (LW) (elevation 3.93 m), *Alnus trabeculasa-Phragmites communis*

(JN-LW) (elevation 3.95 m), *Taxodium distichum-Phragmites communis* (LYS-LW) (elevation 3.92 m), and *Salix matsudana-Phragmites communis* (HL-LW) (elevation 3.93 m) were selected from the ecological construction base of Chongxi Wetland. The elevations of LW, JN-LW, LYS-LW, and HL-LW were basically the same, which were 3.93 m, 3.95 m, 3.92 m, and 3.93 m, respectively. Three 1 m×1 m quadrats were randomly set in *Phragmites communis* for investigation. The other 3 communities were investigated per tree. Results: The average DBH of *Alnus trabeculasa* was 4.5 cm, the average tree height was 480 cm, and the density was about 1.5×2 m. The average DBH of *Taxodium distichum* was 3 cm, the average height was 278 cm, and the density was about 1.5×2 m. The average DBH of *Salix matsudana* was 8 cm, the average height was 420 cm, and the density was about 1.5×2 m. The average height of *Phragmites communis* was 189 cm, the density of *Phragmites communis* was about 68 plants •(1m×1m)⁻¹, with a coverage of approximately 86%.

2.3. Sample collection and preservation

Three average trees were selected from four plots (representative plants were selected by the three-point sampling method in *Phragmites communis*), carefully excavated healthy fine roots (< 4 mm) at depths of 1–15cm, 15–30cm, 30–50cm, and 50–70cm along the plant base, and gently shaken for 1 minute. The soil attached to the root surface of each plant, about 2 mm, was taken as rhizosphere soil, and the soil of the same depth in each field was fully mixed as the rhizosphere soil of different depths of the community. At the same time, non-rhizosphere soil at different depths was collected by similar methods in various fields. The soil samples were put into sealed pockets and brought back to the laboratory. They were quickly air dried, ground, and sieved through an 80 mesh sieve in a cool place, and stored in a wide-mouth bottle at 4°C. The enzyme activity of the sediment soil was to be measured. Samples were investigated and collected on September 7, 2007.

2.4. Determination of soil enzyme activity

Urease activity was determined using the phenol-sodium hypochlorite colorimetric method. Weigh 5.00 g of air-dried soil, add 10 mL of urea solution (10%) and 5 mL of citrate buffer (pH 6.7), and incubate at 37°C for 24 hours. After the reaction, add 1% phenol solution and 0.9% sodium hypochlorite solution, shake well to develop color. Centrifuge and measure the absorbance of the supernatant at 578 nm using a spectrophotometer. Calculate enzyme activity using the NH₃-N standard curve.

Catalase activity was measured by UV spectrophotometry. Weigh 2.00 g of soil, add 40 mL of deionized water and 5 mL of H₂O₂ solution (0.3%), and react at 25°C for 20 minutes. Add 5 mL of sulfuric acid (3 mol/L) to terminate the reaction. Centrifuge and measure the absorbance of residual H₂O₂ in the supernatant at 240 nm using a UV spectrophotometer.

Alkaline phosphatase activity was determined using the phenylphosphate colorimetric method. Weigh 1.00 g of soil, add 5 mL of phenylphosphate solution (0.5%) and 5 mL of borate buffer (pH 9.6), and incubate at 37°C for 1 hour. Add 1 mL of NaOH solution (0.5 mol/L) to terminate the reaction. Centrifuge and add 4-aminoantipyrine solution (0.5%) and potassium ferricyanide solution (0.3%) to the supernatant. Measure the absorbance at 510 nm after color development and calculate enzyme activity using the phenol standard curve.

Protease activity was measured using the Folin-Ciocalteu method. Weigh 2.00 g of soil, add 10 mL of casein solution (2%) and 5 mL of Tris-HCl buffer (pH 7.8), and incubate at 37°C for 2 hours. Add 5 mL of trichloroacetic acid (15%) to precipitate undecomposed protein. Centrifuge and add folin-ciocalteu reagent to the supernatant to develop color. Measure the absorbance at 660 nm and calculate enzyme activity using the tyrosine standard curve.

2.5. Data analysis

All data were statistically analyzed and visualized using SPSS 28.0 and OriginPro 2023.

3. Results

3.1. Physicochemical properties of rhizosphere sediments of different plant communities

The soil pH of each plant community basically increased first and then decreased, and the pH range was between 8.1 and 9.0. It peaked at 30cm depth and then decreased with increasing soil depth, which may be due to the decrease in soil oxygen content with increasing depth (**Figure 2**). However, secretions in the growth regulation process of different species will shape their respective microenvironments, which may be the main reason for the differences in soil pH values of different species (Huang Ru *et al.*, 2016). The soil pH value of each soil layer in the LYS-LW community was the highest, with an average of 8.8, which was significantly higher than that of the other three plant communities. The contents of soil total nitrogen and total phosphorus decreased with soil depth in woody plant communities, but increased in the LW community. The soil total phosphorus content of each plant community was between 550 and 880 mg/kg, and the difference in total phosphorus content was small at different depths. The soil total nitrogen content of each plant community ranged from 200 to 1100 mg/kg, and there were great differences in total nitrogen content at different depths. The average content of total phosphorus and total nitrogen in the soil of the LW community was the highest among the four communities, and the average soil pH value was the lowest. This may be due to the fact that the difference in individual size between woody plants and herbaceous plants is making the demand and consumption of nitrogen and phosphorus by woody plants much greater than that of herbaceous plants, resulting in significantly lower inter-root nitrogen and phosphorus content in woody plants than in herbaceous plants.

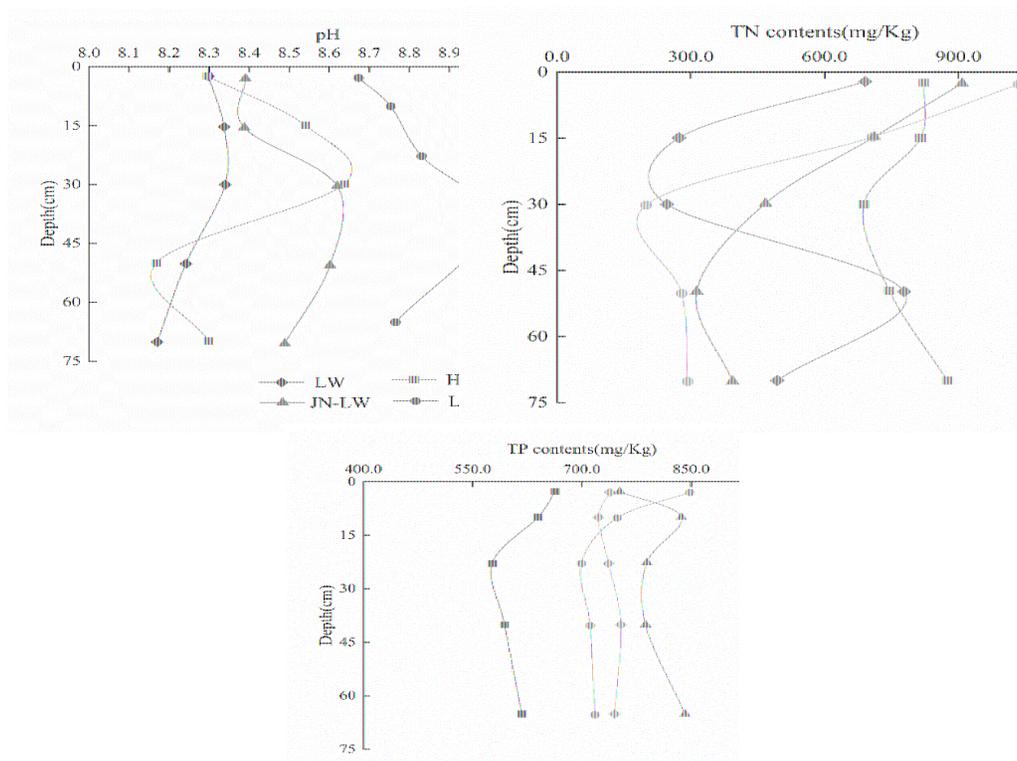


Figure 2. pH, TN, and TP at different depths

3.2. Differences in rhizosphere soil enzyme activity of different plant communities

There were significant differences in rhizosphere soil enzyme activities among different plant communities (Table 1). The soil enzyme activities of the four rhizosphere soil layers of the JN-LW community were higher than those of the other three plant communities. The activity of alkaline phosphatase in the rhizosphere of JN-LW community was $(51.24 \pm 1.41) \mu\text{g} \cdot (100\text{g})^{-1} \cdot (2\text{h})^{-1} (\text{P}_2\text{O}_5)$, which was significantly higher than that of the other three plant communities ($P=0.05$), followed by HL-LW and LYS-LW, and the activity of alkaline phosphatase in the rhizosphere of LW community was the lowest. The order of protease and urease activity in rhizosphere soil of four plant communities was the same: JN-LW>HL-LW>LYS-LW>LW, in which the community protease and urease activities of JN-LW were $(6.90 \pm 0.11) \mu\text{g} \cdot \text{g}^{-1} \cdot (24\text{h})^{-1} (\text{NH}_3\text{-N})$ and $(48.79 \pm 1.52) \mu\text{g} \cdot \text{g}^{-1} \cdot (24\text{h})^{-1} (\text{NH}_3\text{-N})$, respectively. The difference in protease activity was the largest among all communities, and there were significant differences among all communities except the LW community and LYS-LW community ($P=0.01$). The differences in urease activity were relatively small, and only significant differences were observed between JN-LW and LW communities. The catalase activity was also the highest in the JN-LW community, at $(0.53 \pm 0.01) \text{mL} \cdot \text{g}^{-1} \cdot (20 \text{ minutes})^{-1}$ (calculated as $0.1 \text{ mol} \cdot \text{L}^{-1} \text{KMnO}_4$), significantly higher than the other three plant communities ($P=0.05$), while there was no significant difference between the other three plant communities.

Table 1. The soil enzyme activities of four plant communities (\pm SD)

Plant communities	Alkaline phosphatase $/(\mu\text{g} \cdot (100\text{g})^{-1} \cdot (2\text{h})^{-1})$	Proteinase $/(\mu\text{g} \cdot \text{g}^{-1} \cdot (24\text{h})^{-1})$	Urease $/(\mu\text{g} \cdot \text{g}^{-1} \cdot (24\text{h})^{-1})$	Catalase $/(\text{mL} \cdot \text{g}^{-1} \cdot (20\text{min})^{-1})$
LW	36.05 \pm 1.29	4.38 \pm 0.17	19.62 \pm 0.80	0.45 \pm 0.02
JN-LW	51.24 \pm 1.41	6.90 \pm 0.11	48.79 \pm 1.52	0.53 \pm 0.01
LYS-LW	36.98 \pm 1.50	4.63 \pm 0.20	23.24 \pm 2.36	0.45 \pm 0.01
HL-LW	40.84 \pm 1.47	5.60 \pm 0.15	37.88 \pm 1.45	0.46 \pm 0.01

3.3. Vertical distribution of soil enzyme activities in the rhizosphere of different plant communities

As can be seen from Figure 3, the activity of alkaline phosphatase in rhizosphere soil of the four plant communities decreased with the increase of soil depth on the whole, but except for the LYS-LW community, the activity of alkaline phosphatase in rhizosphere soil of the other three plant communities reached its peak at the subsurface layer of 15–30 cm. The mean value of alkaline phosphatase activity in 0–15 cm rhizosphere soil was $51.60 \mu\text{g} \cdot (100\text{g})^{-1} \cdot (2\text{h})^{-1}$, and that in 15–30 cm rhizosphere soil was $52.19 \mu\text{g} \cdot (100\text{g})^{-1} \cdot (2\text{h})^{-1}$. The bottom layer concentration of 50~70 cm was $24.32 \mu\text{g} \cdot (100\text{g})^{-1} \cdot (2\text{h})^{-1}$, decreased by 53.40 %. The urease and protease activities of the four plant communities all showed a decreasing distribution pattern with the deepening of the soil layer, and the magnitude order of the decrease was: JN-LW>LYS-LW>LW>HL-LW. Urease activity changed significantly with soil depth increasing ($P < 0.05$). The urease activity and protease activity in the bottom layer of the four plant communities decreased by 61.93 % and 23.28 % on average compared with the surface layer. Catalase activity did not change significantly with increasing soil depth ($P > 0.05$), but showed an overall upward trend.

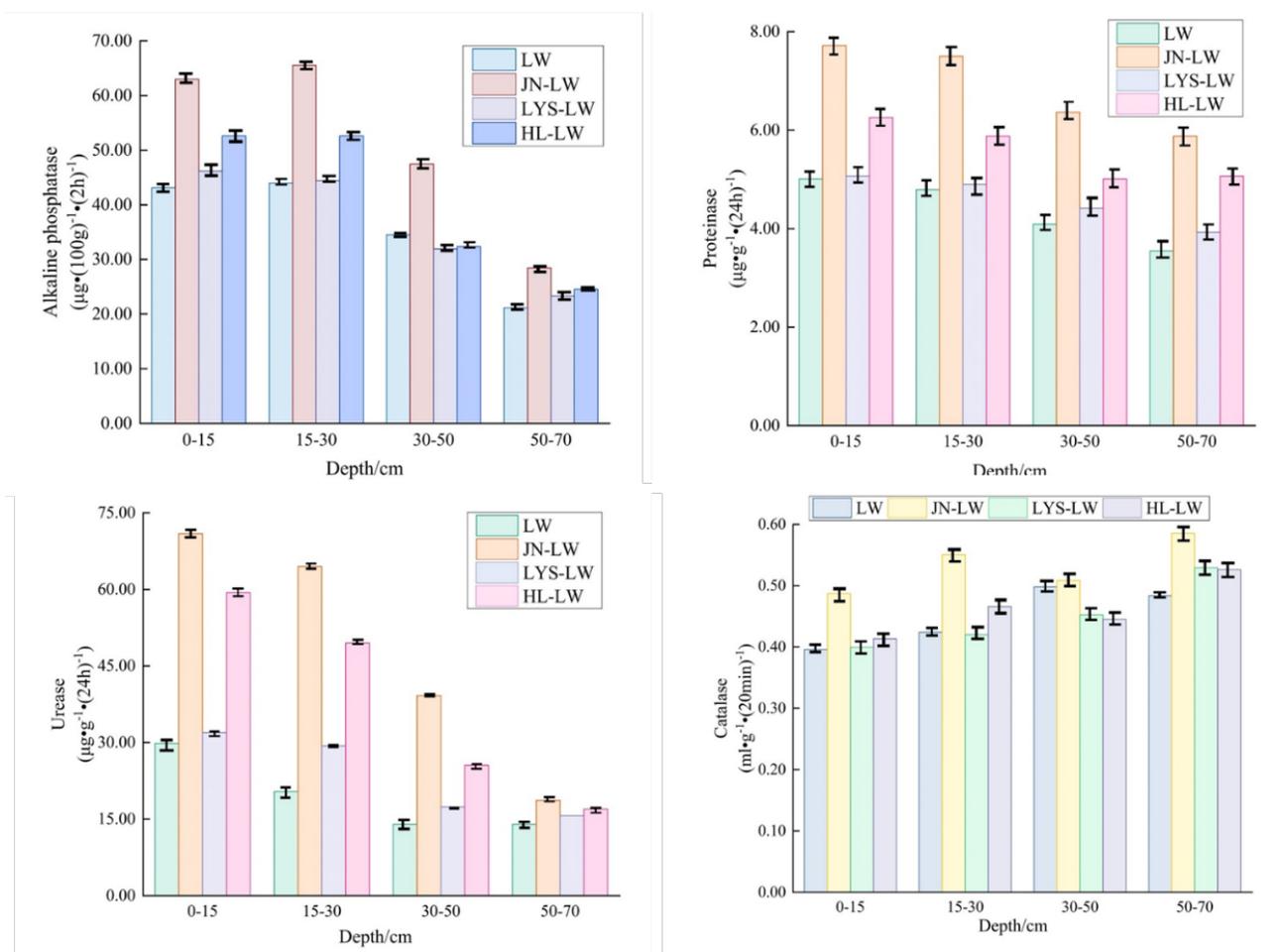


Figure 3. The vertical distribution of the rhizosphere soil enzyme activities of four plant communities

3.4. Differences in enzyme activities between rhizosphere and non-rhizosphere soils

As shown in **Figure 4**, the activities of alkaline phosphatase, protease, urease, and catalase in rhizosphere soil of four plant communities (measured by the average enzyme activities in each soil layer) were significantly higher than those in non-rhizosphere soil ($P < 0.05$). The alkaline phosphatase in rhizosphere soil of LW, JN-LW, LYS-LW, and HL-LW communities was 1.32, 1.66, 1.44, and 1.42 times that of non-rhizosphere soil, respectively. The protease activity in the rhizosphere was 1.07, 1.09, 1.07, and 1.09 times that in non-rhizosphere soil, respectively. The urease activity was 2.61, 2.84, 2.62, and 2.64 times that of non-rhizosphere soil, respectively. Catalase was 1.27, 1.42, 1.25, and 1.06 times higher in non-rhizosphere soil, respectively. In conclusion, the difference in soil enzyme activity between the rhizosphere and non-rhizosphere of the JN-LW community was the most significant, while the difference between the LW community was small. The difference in urease activity between the rhizosphere and non-rhizosphere was the largest, followed by alkaline phosphatase and catalase, and the difference in catalase was the least.

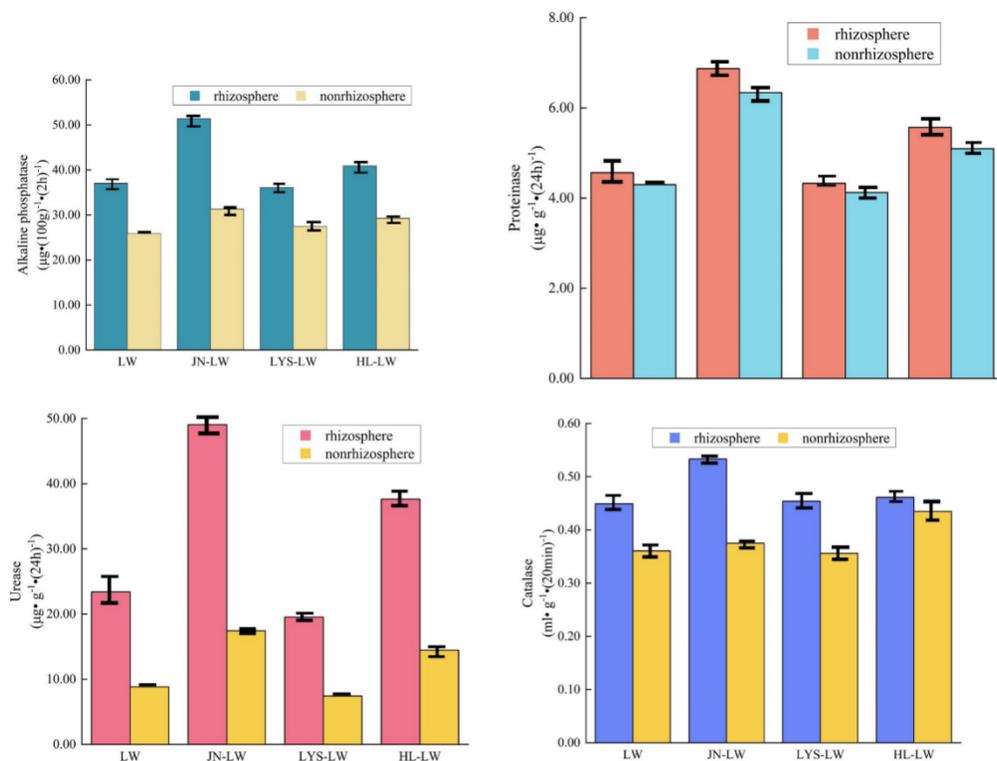


Figure 4. The difference between the rhizosphere and non-rhizosphere soil enzyme activities of four plant communities

4. Discussions

4.1. Effects and significance of the introduction of wet woody plants on soil enzyme activities in the estuarine tidal flat wetland

In general, the alkaline phosphatase, urease, protease, and catalase activities of JN-LW, HL-LW, and LYS-LW communities were higher than those of LW communities, indicating that the introduction of wet woody plants in the tidal flat wetland reed community improved soil enzyme activities, especially the introduction of *Alnus trabeculosa*. At present, there has been no report on the effects of *Alnus trabeculosa* introduced into estuarine tidal flat wetland on soil enzyme activities, but Xie et al. demonstrated that afforestation with nitrogen-fixing species like *Alnus trabeculosa* significantly enhances soil fertility in degraded wetlands [10]. Compared with herbaceous plants, woody plants increased soil enzyme activity more significantly, which may be related to the developed root system of woody plants. Plant root activities have a great impact on plant growth and soil biological activity, and there is a close material and energy conversion between plant roots and soil. Relevant studies have shown that the length and density of root hairs and the active degree of roots of plants all determine the size of the rhizosphere range to a certain extent. The extension of plant roots affects the stability, hydrophobicity, and porosity of soil aggregates [11]. Plant roots extend along the direction of least resistance, and root interpenetration and compression enhance the stability of rhizosphere soil aggregate structure to improve soil nutrient buffering performance, thus affecting water and nutrient supply in rhizosphere soil [12]. In the rhizosphere environment, plant root activities not only provide abundant material and energy sources for soil microorganisms but also affect their growth, metabolism, and distribution, thereby regulating the release of soil enzymes [13].

Alkaline phosphatase can promote the hydrolysis of soil organic phosphorus compounds and convert them into inorganic phosphorus that can be absorbed and utilized by plants, and its activity reflects the potential capacity of soil to supply available phosphorus^[14]. Therefore, the introduction of wet woody plants is conducive to improving the activity level of alkaline phosphatase in soil, thus improving the hydrolysis ability of organic phosphorus. Its introduction plays an important role in improving the availability of soil organic phosphorus.

Urease can promote the hydrolysis of peptide bonds in organic matter molecules, and its product is the most important soil-available nitrogen for plants. The increase in soil urease activity indicates that the decomposition degree of organic detritus in soil is enhanced, and as a result, the content of organic nitrogen in soil is increased. It can be seen that the introduction of wet woody plants is beneficial for the occurrence and progress of urease-catalyzed reactions and is conducive to the conversion of available nitrogen in the soil, which plays an important role in promoting nitrogen fixation and soil improvement.

Protease plays an important role in the hydrolysis of amino acids, proteins, and nitrogenous organic compounds in soil, and the final product amino acids, are important substances required for plant growth. The soil protease activity in the mixed community of wet woody plants and *Phragmites communis* was higher than that in the LW community, indicating that the introduction of wet woody plants was beneficial to the conversion of amino nitrogen in soil and promoted plant growth.

Catalase can decompose the hydroperoxide in the soil, promote the redox reaction in the soil, and improve the soil ventilation, water utilization, and soil structure. Among the four plant communities, the rhizosphere soil catalase activity in the JN-LW community was the highest, which was also significantly higher than that in non-rhizosphere soil. It can be seen that the introduction of woody plants in wetlands can enhance soil permeability and improve the aeration conditions of plant roots, and facilitate the growth and development of plant roots. To a certain extent, the soil condition of estuarine tidal flat wetland can be improved, and the stability of the ecosystem can be maintained.

4.2. Genetic analysis of the spatial distribution of plant rhizosphere soil enzyme activities in estuarine tidal flat wetland

There was no significant change in catalase, which was basically consistent with previous research results^[15-16]. Recent studies on microbial community dynamics revealed that depth has a strong influence on soil enzyme activities, and soybean soil enzyme activities show strong stratification, which is known as plant-driven stratification^[16]. The soil enzyme activities of JN-LW and LYS-LW communities decreased the most with the increase of soil depth, which may be due to the fact that *Alnus trabeculasa* and *Taxodium distichum* have not been introduced for a long time, and the root system is not developed. With the increase in soil depth, the physiological and metabolic diversity decreased, and the main microbial species also changed, resulting in differences in the spatial distribution of enzyme-secreting microorganisms (especially fungi and bacteria). It may be the cause of the difference in the spatial distribution of enzyme activities. In addition, the substrate, such as litter and β -glucosidase in the surface layer of tidal flat wetland soil, was more abundant than that in the deep soil, which also maintained the higher enzyme activity in the surface layer of soil.

4.3. Effects of plant roots on soil enzyme activities in the Estuarine tidal flat wetland

The activities of alkaline phosphatase, urease, protease, and catalase in rhizosphere soil of four plant communities were higher than those in non-rhizosphere soil, which was consistent with previous research results on other plants^[6, 17]. Plant roots transfer carbon, nitrogen, and bioactive metabolites to the soil through rhizodeposition, leading to alterations in soil pH and nutrient availability, thereby creating distinct physicochemical

and biological gradients between rhizosphere and bulk soils ^[18]. Globally, 28%–59% of plant photosynthates are allocated belowground, with 40%–70% entering the soil as root exudates. These exudates establish a unique “rhizosphere” microdomain—a hotspot for microbial activity and enzyme production within millimeters of root surfaces ^[19]. Plant root secretions include several enzymes such as phosphatase, invertase, amylase, protease, and polygalacturonase ^[19]. Some studies have also shown that most phosphatases may come from plant roots ^[20]. In addition, plant roots can also affect enzyme activity through some indirect effects, for example, plant roots can affect enzyme activity by providing C secretions to enzymes producing microorganisms ^[16]. The root system of *Alnus trabeculasa* has a significant impact on soil enzyme activity, but its mechanism needs further research. By using fluorescent enzyme substrates and microscopy techniques, it is possible to identify differences in the impact of plant roots on soil enzyme activity when observed very close to the roots.

5. Conclusions

- 1) The activities of alkaline phosphatase, protease, urease, and catalase in the rhizosphere soil of the JN-LW community were higher than those of other plant communities, while the four soil enzyme activities in the LW community were the lowest.
- 2) The vertical distribution of extracellular enzyme activities in the rhizosphere of the four plant communities was consistent. The activities of protease and urease decreased significantly with the increase of soil depth, and the average urease decreased by 61.93%, which was the most significant decrease. Alkaline phosphatase activity decreased with the increase of soil depth, but the peak value appeared in the subsurface layer of 15~30 cm. Catalase activity did not change significantly with soil depth.
- 3) The comparative study of extracellular enzyme activities in the rhizosphere and non-rhizosphere of the four plant communities showed that extracellular enzyme activities in the rhizosphere of the four plant communities were higher than those in the non-rhizosphere.
- 4) The introduction of *Alnus trabeculasa* significantly increased soil enzyme activities closely related to soil material cycling, which is of great significance for improving soil conditions and improving the purification function of the estuarine tidal flat wetland. Therefore, *Alnus trabeculasa* is a suitable species for the ecological restoration of estuarine tidal flat wetland, and has a broad application prospect in the ecological restoration of estuarine tidal flat wetland.
- 5) Compared with the natural tidal flat, the artificial forest in the estuarine tidal flat had higher extracellular enzyme activity. Moist woody plants with well-developed roots can improve the extracellular enzyme activity of estuarine tidal flat wetland, especially plants with mycorrhiza.

Disclosure statement

The author declares no conflict of interest.

Reference

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