Journal of Cleaner Production 328 (2021) 129581

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Preferential flow improves root-soil system on a small scale: A case study of two ecotypes of *Phragmites communis*

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ARTICLE INFO

Handling editor: Bin Chen

Keywords:
Root architecture
Soil nutrient
Preferential flow
Phragmites communis
Yellow River Delta

ABSTRACT

The effects of preferential flow on plant root and soil have not been deeply studied. Research on the combination of wetland vegetation, hydrology, and soil can provide a theoretical basis for wetland vegetation restoration and soil salinization control. We integrated preferential flow, root, and soil to study the distribution characteristics of the root architecture and soil nutrient of two different ecotypes of *Phragmites communis* (*P. communis*) in the Yellow River Delta on a small scale. We found that both root architectures included root length, width, surface area, volume, and biomass and soil nutrients included soil organic carbon, organic matter and total nitrogen decreased with the increase of soil depth. Large *P. communis* (LP) not only had significantly larger root length, width, surface area, but also had significantly higher soil organic carbon, organic matter, total nitrogen, and available phosphorus than small *P. communis* (SP). The root architectures of SP in the preferential flow area (PFA) were significantly greater than those in the matrix flow area (MFA). The contents of soil organic carbon, organic matter, and total nitrogen in LP grown in the PFA were obviously higher than those in the MFA. Based on correlation analysis, root architectures had remarkably positive correlations with soil organic carbon, organic matter, and total nitrogen. These findings suggest that preferential flow improves the root-soil system. By artificially adding peat and biochar and changing irrigation methods, the possibility of preferential flow can be increased, plant root growth and soil nutrient can be improved, so as to resist the damage of soil salinization. In addition, different ecotypes of *P. communis* should be planted to improve soil salinization. LP and SP are suitable for slight and heavy soil salinization areas respectively.

1. Introduction

Wetland is considered as a transitional area between terrestrial and aquatic ecosystem (Brinson, 1993). It plays an important role in maintaining biodiversity (Barbieri et al., 2013) and provides rich ecological and economic services for humans (Barbieri et al., 2013; Bella et al., 2020). However, climate change and human activities aggravate wetland degradation. The destruction of wetland health causes major ecological and social problems, resulting in a decrease in biodiversity and species richness, and the frequent occurrence of salt dust storms, soil erosion, soil moisture, and nutrient loss, and changes in hydrological elements between wetland patches which affect wetland hydrological connectivity (Kim and Mohanty, 2017; Mitchell et al., 2013) and wetland hydrological cycle processes (Craft et al., 2009).

Wetland is a combined system of elements that includes vegetation, hydrology, and soil (Cronk and Fennessy, 2001). The stability of the wetland vegetation-soil-hydrology system directly affects the health and balance of the wetland ecosystem. As a key factor in the “vegetation-soil-hydrology” system (Rodríguez et al., 2017; Rodriguez-Iturbe and Porporato, 2002), vegetation has a significant impact on soil and hydrology. Vegetation has a significant influence on the redistribution of soil water because water can rise from deep soil layers to surface layers through plant transpiration. The roots of plants are deeply distributed in arid areas, but plants consume a large amount of water through transpiration. Roots absorb deep water in the soil to maintain their growth and affect the balance of soil groundwater at depth (Priyadarshini et al., 2016). At the same time, water can flow vertically and horizontally along the root system. Water redistribution directly causes spatial

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https://doi.org/10.1016/j.jclepro.2021.129581
Received 25 June 2021; Received in revised form 3 October 2021; Accepted 2 November 2021
Available online 4 November 2021
0959-6526/

heterogeneity of soil nutrients, organic matter, and microbial activities. As an essential organ for vegetation growth, the root system plays a vital role in maintaining the balance and healthy operation of ecosystems (Brubaker and Norton, 1996; Revelli and Ridolfi, 2003).

Hydrology also plays a decisive role in wetland ecosystem (Gao et al., 2017). The identification process of wetland hydrological characteristics is complex and cannot be judged by the soil moisture content of wetlands. Preferential flow is a sign of the transport of water and solutes from homogeneous to heterogeneous research and represents an unbalanced flow process of unbalanced flow. Water and solutes bypass the soil matrix area and rapidly penetrate into the soil layer. As a result, preferential flow path has much higher water flow and solute transport rates than those in the matrix area (Beven and Germann, 1982; Hendrickx and Flury, 2001). At the same time, this phenomenon causes rapid transport of water and solutes, reduces water-solute interaction with the pores of the surrounding soil matrix within the preferential flow path, and eliminates the supply of water and nutrients to arid land (Niu et al., 2006). Many factors, including soil texture, soil structure, soil porosity, soil water repellency, soil bulk density, soil organic matter, vegetation roots, gravel, solute application acceleration rate, irrigation, tillage, and dry wet freeze-thaw conditions, affect the preferential flows (Zhang et al., 2016). Few studies have focused on the effects of preferential flow on root and soil. Relevant studies simply analyzed the relationship between preferential flow and root density (Bundt et al., 2001). At the same time, the research area mainly focuses on forests (Bundt et al., 2001) and agricultural land (Fuhrmann et al., 2019), and there is less research on wetlands.

Soil drought and water scarcity in wetland ecosystems reduce the content of soil organic matter by promoting microbial decomposition (Liao and Song, 2009). At the same time, decreased soil organic matter content also leads to reduced soil moisture content, which affects the water retention capacity and tends to dry the surface of wetland soil (Liao and Song, 2009). Most importantly, it leads to a significant reduction in organic matter cementation, reduced cohesiveness of soil particles, soil shrinkage due to drought and water scarcity, and the formation of wide and deep fissures in the soil (Ma et al., 2015). Fissures can promote the occurrence of preferential flow (Larsbo et al., 2016; Luo et al., 2010; Romkens and Prasad, 2006; Sanders et al., 2012). In areas with severe industrial and agricultural pollution, pollutants, pesticides, and fertilizers take the preferential flow formed by fractures as carriers that penetrate the soil layer quickly and reach the groundwater layer. This process increases the risk of regional groundwater pollution and endangers human survival and health (Naveed et al., 2015). Therefore, soil structure can affect preferential flow, but there is a lack of study on the effect of preferential flow on soil nutrient.

From the above contents, it can be concluded that plant roots, as an important plant organ, have an important impact on soil moisture and structure, and soil conditions further affect preferential flow. However, how preferential flow affects plant root architecture and soil nutrient has not been deeply studied. In addition, multi-scale analysis of wetland hydrological movement should be carried out. Preferential flow, as a small-scale hydrological movement, will affect wetland hydrological movement on a larger scale. The study of how preferential flow affects plant root architecture and soil nutrient is a process of coupling the three important elements of vegetation, hydrology, and soil in wetland, which plays an important role in wetland restoration and management.

The Yellow River Delta wetland is the youngest in the world and has the highest potential to be developed (Gao et al., 2015). However, in recent years, the ecological environment of the Yellow River Delta wetland has deteriorated. The main ecological problems faced by the Yellow River Delta wetland is lack of water resources, wetland degradation, and soil salinization. The above problems will directly affect the balance of the vegetation-soil-hydrology system. In particular, soil salinization, an environmental pollution problem, has seriously affected wetland plant growth and diversity. The reverse succession rate from freshwater wetland to salt marsh wetland has been accelerated. It has a negative impact on the sustainable development of wetlands. Thus, it is very important to study the relationships among plant, soil, and hydrology.

This research targets *Phragmites communis*, a typical plant in the Yellow River Delta, to analyze how preferential flow affects root architecture and soil nutrient in the underground rhizosphere of two ecotypes of *P. communis*. Specifically, the root architecture and soil nutrient at various depths in the preferential flow area (PFA) and the matrix flow area (MFA), and the relationships between them were investigated. Based on current research, a deeper understanding of the impact of preferential flow on root-soil system is given, and theoretical guidance for wetland vegetation restoration and soil salinization management in the Yellow River Delta is also provided.

2. Materials and methods

2.1. Study site

The study area is located in the Yellow River Delta Nature Reserve (37°35′–38°12′N, 118°33′–119°20′E), which is located in Dongying City, Shandong Province, China (Zhao et al., 2019). The nature reserve belongs to the warm temperate continental monsoon climate, characterized by cold winter and hot summer, with four distinct seasons. The annual average temperature is 12.4 °C and the annual average precipitation is 551.6 mm (Zhao et al., 2015).

The field survey was conducted in July 2019. The distribution areas of two ecotypes of *Phragmites communis,* including large *P. communis* (LP) and small *P. communis* (SP), were selected, and three 1.0 m × 1.0 m plots were set for each type of *P. communis*. The vegetation growth conditions, including plant height and coverage, were recorded. Vertical sections were excavated around each sample plot, and soil samples (0–10, 10–20, 20–30, and 30–40 cm) were taken from four layers. All soil samples were sealed and brought back to the laboratory to measure soil properties, including soil water content, porosity, pH, and electrical conductivity.

2.2. Dye tracing experiment

As shown in Fig. 1, we used the brilliant blue solution (4 g/L) to trace the PFA and MFA. The stained area was considered the PFA, and the unstained area was considered the MFA. After using the brilliant blue solution for 24 h, vertical and transverse sections were excavated. The distance between vertical section slices was 10 cm. A total of four vertical sections were excavated. The depth of the vertical section was dependent on the maximum dyeing depth of brilliant blue. The setting method of the transverse section was the same as that of the vertical section. After dyeing, the vertical profile was divided into two areas: the PFA and the MFA. A standard ring cutter (100 cm^3) was used to sample both areas, and the soil depth gradient was 10 cm. Sampling was repeated three times for each soil layer. The sampling method of the transverse section was the same as that of the vertical section. Root and soil samples were placed in a refrigerator (4 °C) for analysis.

2.3. Root and soil nutrient analysis

The water washing method was used to obtain root samples. The roots washed with water were placed in an oven at 85 °C for 24 h for drying (Deignan and Lewis, 2010; Talboys et al., 2014). Then, root architecture indexes, including root length, width, surface area, volume, and biomass, were measured by Rootanalysis software (PM-Tech GmbH, Germany). Soil indexes included organic carbon, organic matter, total nitrogen, and total phosphorus.

2.4. Statistical analysis

SigmaPlot 12.5 software was used for figures. SPSS 19.0 software

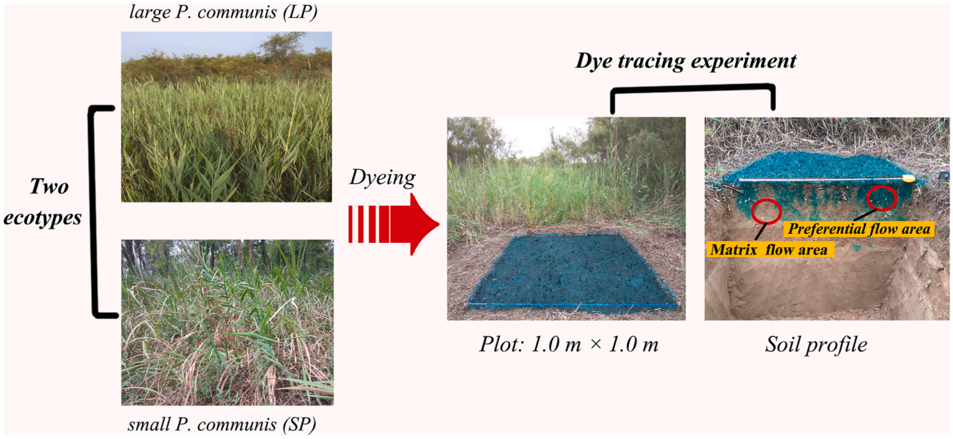

Fig. 1. Dye tracing experiment.

was used to perform the One-way ANOVA, *T*-test, and Pearson's correlation analysis. One-way ANOVA was used to explore the differences of root architecture and soil nutrients among different soil depths. *T*-test was used to explore the differences of root architecture and soil nutrients between the two ecotypes of *P. communis*. At the same time, *t*-test also analyzed the differences of root architecture and soil nutrients in different areas: the PFA and the MFA. Pearson's correlation analysis was used to determine the relationship between root architecture and soil nutrients.

3. Results

3.1. Plant growth and soil characteristics

Table 1 shows the plant growth characteristics of different vegetation types. The LP height was 1.9–2.0 m, and the coverage was about 98%. The SP height was 1.9–2.0 m, and the coverage was about 70%. In terms of height and coverage, SP was significantly lower than that of LP.

Table 2 shows the soil properties of different types of *P. communis*. Differences in soil water content and soil porosity were not significant. The pH values of the two soils were alkaline, and the alkalinity of the LP soil was higher than that of SP. However, the soil electrical conductivity of SP was much higher than that of LP. Soil water content and soil salinity are the two most important factors affecting changes in soil electrical conductivity. In our study, there was no significant difference in soil water content. Thus, the soil salinity of SP was much higher than that of LP.

The results showed that the growth of the aboveground parts of the two ecotypes of *P. communis* was different, and the difference in soil salinity was also very significant. Therefore, this study further focused on the underground part of the plants, that is, differences in root growth and soil nutrient.

3.2. Distribution of root architecture

We statistically analyzed the root structure of the rhizosphere throughout the wetland and analyzed the response of large and small *P. communis* to the profile scale and regional scale (PFA and MFA) of the entire field. At the same time, the total length, width, total surface area, total volume, and biomass of the root system of unit soil were counted to evaluate the distribution characteristics of the root architecture in the wetland rhizosphere. Fig. 2 shows the quantitative analysis of the root architecture of both LP and SP in the Yellow River Delta wetlands.

With the increase of soil depth, the total root length, width, surface area, volume, and biomass per unit soil decreased. SP root lengths differed significantly among different soil depths in both the PFA ($P = 0.008$) and the MFA ($P = 0.015$). LP root volume densities in the PFA ($P = 0.041$) and MFA ($P = 0.005$) were also significantly different among different soil depths. The root surface area densities of LP ($P = 0.042$) and SP ($P = 0.002$) in the PFA were significantly different among different soil depths. The densities of root volume ($P = 0.026$) and biomass ($P = 0.018$) of SP in the PFA had significant difference among different soil depths. But the root widths of LP and SP showed no significant difference among different soil depths.

The root width, surface area, volume, and biomass in the PFA were higher than those in the MFA. The root width ($P = 0.014$), surface area ($P = 0.001$), volume ($P = 0.001$), and biomass ($P = 0.002$) between the PFA and MFA of SP were significantly different. The root length of SP in the PFA was larger than that in the MFA, the root length of LP in the PFA was smaller than that in the MFA. There was a significant difference in the root length of SP ($P = 0.007$). No significant difference was observed in the root length between the two areas of LP ($P = 0.885$).

The root length ($P = 0.023$) and width ($P = 0.045$) of LP were larger

Table 1
Plant growth characteristics of two ecotypes of *P. communis*.

Plants	Plot	Average height (m)	Coverage (%)
LP	1	1.9	98
	2	2.0	98
	3	1.9	98
SP	1	0.6	70
	2	0.5	70
	3	0.5	70

Table 2
Soil properties of two ecotypes of *P. communis* in different soil depths.

Plants	Soil properties	Soil depth (cm)			
		0–10	10–20	20–30	30–40
LP	SWC (g/kg)	0.260 ± 0.058	0.218 ± 0.027	0.234 ± 0.022	0.221 ± 0.020
	SP (g/cm^3)	0.571 ± 0.026	0.479 ± 0.013	0.475 ± 0.020	0.453 ± 0.031
	pH	8.960 ± 0.053	9.063 ± 0.246	9.137 ± 0.170	8.983 ± 0.304
	SEC (us/cm)	114.200 ± 26.800	145.500 ± 111.300	209.100 ± 71.900	387.000 ± 125.400
SP	SWC (g/kg)	0.236 ± 0.004	0.223 ± 0.014	0.199 ± 0.052	0.251 ± 0.003
	SP (g/cm^3)	0.487 ± 0.004	0.475 ± 0.016	0.471 ± 0.018	0.488 ± 0.003
	pH	8.470 ± 0.175	8.583 ± 0.242	8.803 ± 0.186	8.703 ± 0.182
	SEC (us/cm)	1160.000 ± 104.100	770.700 ± 125.700	712.300 ± 227.800	996.300 ± 716.500

SWC: soil water content; SP: soil porosity; SEC: soil electrical conductivity.

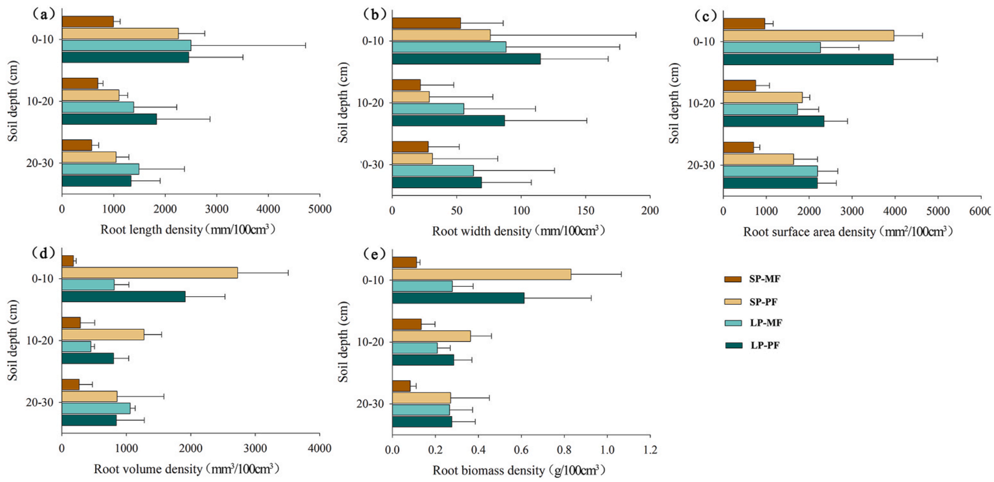

Fig. 2. Changes in two ecotypes of *P. communis* root architecture in PFA and MFA at different soil depths.

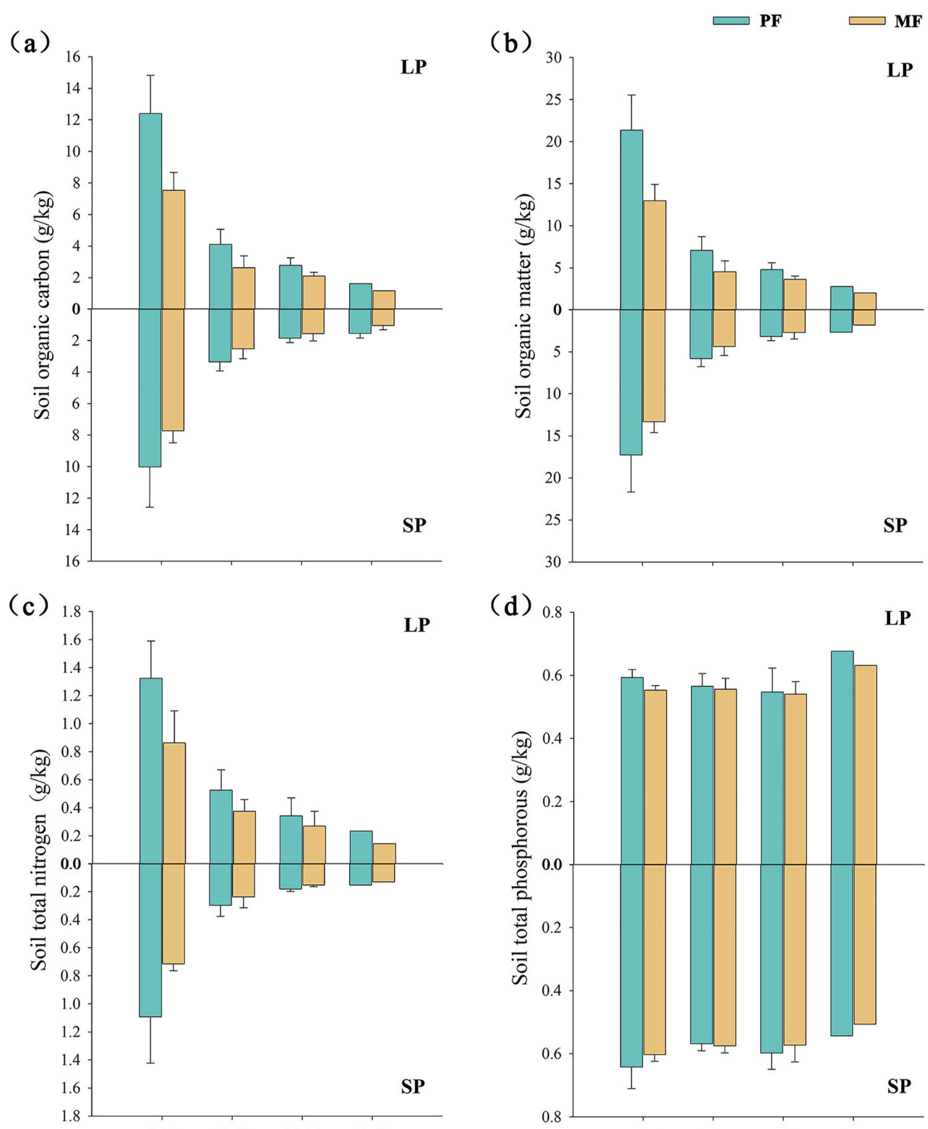

Fig. 3. Changes in soil nutrients of two ecotypes of *P. communis* in PFA and MFA at different soil depths.

than those of SP. Moreover, the root surface area of LP was significantly higher than that of SP ($P = 0.032$). But the differences of root volume and biomass between LP and SP were not noticeable.

In summary, root length, width, surface area, volume, and biomass showed a nonlinear decreasing trend with increasing soil depth. The root length, width, surface area, volume, and biomass of SP were significantly larger in the PFA than in the MFA. LP had significantly larger root length, width, and surface area than SP.

3.3. Distribution of soil nutrient

Fig. 3 shows the variation of soil nutrients with soil depth in the PFA and MFA of two *P. communis*. Soil organic carbon ($P = 0.000$) and soil organic matter ($P = 0.000$) decreased with increasing soil depth, all differences being noticeable. Soil organic carbon ($P = 0.000$) and soil organic matter ($P = 0.000$) in the PFA were significantly higher than those in the MFA at the same soil depth of LP. Moreover, soil organic carbon ($P = 0.005$) the soil organic matter ($P = 0.005$) of LP were considerably higher than those of SP.

For LP and SP, the total nitrogen content in the PFA was 0.607 ± 0.493 g/kg and 0.374 ± 0.378 g/kg, respectively. In comparison, the total nitrogen content in the MFA was 0.413 ± 0.314 g/kg and 0.266 ± 0.259 g/kg, respectively. There was a significant difference in soil total nitrogen content between LP and SP ($P = 0.000$). Meanwhile, soil total nitrogen content decreased with increasing soil depth, and the difference among different soil depths was significant ($P = 0.000$). At the same soil depth, the total nitrogen content of LP in the PFA was significantly higher than that in the MFA ($P = 0.001$).

Soil total phosphorus of LP was significantly different among different soil depths in PFA ($P = 0.017$) and MFA ($P = 0.043$). At the same soil depth, there was a significant difference in soil total phosphorus content between the PFA and MFA for LP ($P = 0.011$). The total phosphorus content of LP was slightly higher than that of SP, but the difference was not significant.

In general, the soil organic carbon, organic matter, and total nitrogen decreased with increasing soil depth. The soil organic carbon, organic matter, total nitrogen, and available phosphorus in LP were significantly higher than those in SP. Soil organic carbon, organic matter, and total nitrogen of LP at the same soil depths were significantly higher in the PFA than in the MFA. However, as soil depth increased, the range of total phosphorus variation was small, and there was no significant difference in soil total phosphorus content between LP and SP. Moreover, the difference between the PFA and MFA in the total phosphorus content at the same soil depths was not significant.

4. Discussion

4.1. Root and soil differences between two ecotypes of *P. communis*

Not only was the aboveground height and coverage of the LP higher than that of the SP, but the underground root architecture was better than that of the SP. Root architectural characteristics include root length, width, surface area, volume, and biomass. The LP indicators above were larger than those of SP, with significant differences in root length, width, and surface.

The contents of soil organic carbon, organic matter, and total nitrogen of LP were significantly higher than those of SP. This is presumably because the organic matter in the LP surface layer is mainly caused by the decomposition of litter on thick surfaces. The soil microbial activity is high, and the decomposition of vegetation litter is strengthened. Surface aggregation of vegetation litter can protect the integrity of the soil structure. At the same time, the content of the root system in the surface vegetation of the soil is high, and the root system intersects in the surface layer of the soil. Organic matter continuously secreted during root growth. Therefore, the soil nutrient content of LP was high.

P. communis has a very wide range of ecological adaptability (Gao et al., 2015). It grows not only in groups and large areas in phreatic swamps but also in seasonal pond environments. At the same time, it can grow on both low-salt and high-salt soils. In our study, the electrical conductivity of the soil where SP grew was significantly higher than that of LP. This may be the reason why LP height and coverage were considerably higher than those of SP. Meanwhile, the above results also show that LP root length, width, and surface area are significantly higher than those of SP. Further analysis of the root and soil distribution characteristics of different ecotypes of *P. communis* can provide a reference for favorable conditions of its growth.

Using ecological measures to improve salinization is an important direction of soil salinization improvement. *P. communis* can adapt to high salt environment by adjusting the solute penetration level of leaves (Lissner and Schierup, 1997). Moreover, *P. communis* has a strong regulatory effect on the structure and function of wetland ecosystems (Duan, 2004; Guo, 2003). Planting *P. communis* is a good choice to improve soil salinization in the Yellow River Delta. In the long-term evolution process of *P. communis* populations in different habitats, their morphological and physiological characteristics have changed to varying degrees due to different environments, so as to form different ecotypes of *P. communis* to deal with various environmental pressure (Bella et al., 2020). Therefore, we can improve the pollution of soil salinization in the Yellow River Delta by planting different ecotypes of *P. communis* in different areas with different environmental conditions. In this study, LP and SP are suitable to live in areas with slight and heavy soil salinization respectively. Different ecotypes of *P. communis* (LP and SP) can be planted in different areas to alleviate the problem of soil salinization, which is conducive to wetland restoration and sustainable development.

4.2. Spatial distribution of root-soil characteristics

Our study showed that the root system in the rhizosphere of the Yellow River Delta wetland had surface aggregation. The root content was the highest at soil depths of 0–10 cm, which was consistent with previous studies (Glab, 2013; Himmelbauer et al., 2010; Lipiec et al., 2003). At the same time, root content showed a nonlinear decreasing trend with increasing soil depth, which was consistent with related studies (Bogner et al., 2010; Mosaddeghi et al., 2009). The highest root system content was found at soil depths of 0–10 cm. This is thought to be due to the high water and nutrient contents at this depth, where water and nutrients provide the necessary conditions for vegetation root growth. The content of root system at depth was lower, which may be associated with higher salt content in deep soil layers of the Yellow River Delta. The vegetation root system is rich in surface soil layers, which can effectively mitigate the harmful effects of soil salinization on the vegetation root system and promote the healthy growth of vegetation.

The results also showed that the root architecture in the PFA was noticeable, and the difference was significant for SP. The main reasons are as follows: (1) the root system is mainly distributed in the soil surface layer, the roots are the most abundant (Glab, 2013; Himmelbauer et al., 2010; Lipiec et al., 2003), and the interaction between roots, and between roots and soil forms a complex network that promotes the formation of soil macropores (Van Noordwijk et al., 1993). The root system also improves soil structure, increases soil macropore density (Shi et al., 2012) and macropore hydrological connectivity (Cannavo and Michel, 2013), and reduces soil bulk density. As a result, the compacted soil becomes more relaxed (Lin et al., 2010). Therefore, the dyeing effect of the soil surface layer was noticeable, and the dyed area ratio was relatively large. However, in deep soil, the root content is low, root growth is difficult to penetrate deep soil layers under mechanical pressure, the large pore density of deep soil layers is small, and the color effect is not remarkable; (2) the root system can release complex organic matter, such as amino acids, organic matter, acids, sugars, and enzymes into the soil layer. These organic substances can lubricate the part of the root wall in contact with the soil, promote root growth in a compact soil layer (Bengough, 2012), and the macropore density of the soil layer is indirectly affected; and (3) the root pore channels formed by dead roots were more easily connected to the surrounding pore network due to the death, decay, and physical decomposition of the root system, promoting the dyeing effect (Zhang et al., 2015).

In our study, the contents of soil organic carbon, organic matter, and total nitrogen decreased gradually with increasing soil depth, but differences in total phosphorus content at different soil depths were not significant, which is consistent with relevant studies (Xiao et al., 2018; Zibilske et al., 2002; Zou et al., 2018). Moreover, the results also indicated that the contents of soil organic carbon, organic matter, total nitrogen, and total phosphorus in the PFA were higher than those in the MFA. The higher the root content, the stronger the physiological activity of the root, and the higher the capacity of the root to absorb nutrients. At the same time, organic compounds were released into the rhizosphere during root growth. Root exudates affect the availability of nutrients in the rhizosphere and alter the physical, chemical, and biological characteristics of the rhizosphere. This results in higher nutrient contents in the PFA than in the MFA. Next, the surface litter of the soil surface reforms stable organic colloidal humus after microbial decomposition. This can result in the release of free humic acid and humic acid salts. Humus is an essential organic matter in soil. Soil water carries materials and other substances in the preferential flow path and can be retained by the pipe walls of the path, resulting in increased nutrient contents in the PFA.

Preferential flow improves root growth and soil nutrient. By increasing the occurrence of preferential flow, root growth can be promoted and soil nutrient can be further improved. In addition, the growth of plant roots can also alleviate the harmful effects of soil salinization on plants. Preferential flow can be increased by artificially adding peat, biochar, organic fertilizer (Clough et al., 2013). In addition, irrigation methods (Ren et al., 1996) and soil animals (Andreini and Steenhuis, 1990; Natsch et al., 1996) also affect preferential flow.

4.3. Interactions between root architecture and soil nutrient

As shown in Fig. 4, root architecture indexes, including root length, width, surface area, volume, and biomass, showed significant positive correlations. Among all, the correlation coefficients of length, width, and surface area were high, and those of surface area, volume, and biomass were high. Soil properties of organic carbon, organic matter, total nitrogen, and total phosphorus also showed significant positive correlations. Among all, the correlation between organic carbon, organic matter, and total nitrogen was high.

There were significant positive correlations between root characteristics and soil organic carbon, soil organic matter, and soil total nitrogen, but not soil total phosphorus. Specifically, there was no significant correlation between the length and width of the root system and total phosphorus. However, there was a significant positive correlation between root surface area, volume, biomass, and soil total phosphorus content.

In this study, root architecture and soil nutrient in a mixed root-soil system interacted with each other. Roots which absorb water and nutrients from the soil are important organs for plants (Ali et al., 2018). Higher soil organic carbon, organic matter, and total nitrogen can improve root architecture.

5. Conclusions

In this study, we analyzed the spatial distribution characteristics of root and soil in the rhizosphere of the underground part of two ecotypes of *P. communis*. We focused on changes in root architecture and soil nutrient at different depths in the PFA and MFA to provide a basis for improving the wetland soil salinization.

Our research shows that root architecture and soil nutrient vary by

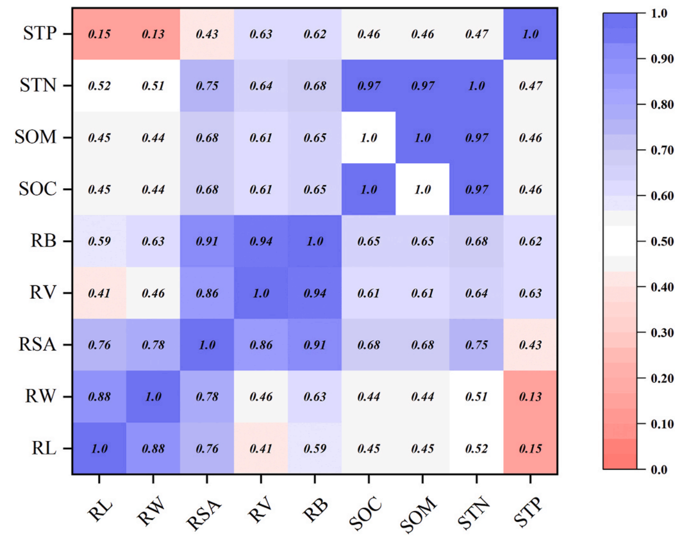

Fig. 4. Correlations between root architecture and soil nutrient. (Each cell indicates the correlation of its corresponding horizontal and vertical coordinates, the numbers in the cells represent correlation coefficient, and the color represents *P* value. STP: soil total phosphorous; STN: soil total nitrogen; SOM: soil organic matter; SOC: soil organic carbon; RB: root biomass; RV: root volume; RSA: root surface area; RW: root width; RL: root length.)

soil depth and region, including PFA and MFA. Root length, width, surface area, volume, and biomass decreased as soil depth increased. Soil organic carbon, organic matter, and total nitrogen also tended to decrease with increasing soil depth. The SP root architecture in the PFA was significantly greater than that in the MFA. Soil organic carbon, organic matter, and total nitrogen of LP at the same soil depths in the PFA were considerably higher than those in the MFA. Besides, there were significant positive correlations between root architecture and soil nutrient. Thus, preferential flow improved the root architecture and soil nutrient.

In order to alleviate soil salinization in the Yellow River Delta, we believe that different ecotypes of *P. communis* (LP and SP) should be planted according to the different situation of soil salinization, LP and SP are suitable for slight and heavy soil salinization areas respectively. In addition, the probability of preferential flow can be increased by artificially adding peat and biochar and changing irrigation methods, so as to improve plant root growth and soil nutrient. On this basis, we can improve the pollution of soil salinization, restore the wetland and ensure its sustainable development.

CRediT authorship contribution statement

Yanan Wu: Conceptualization, Investigation, Writing – original draft. **Yinghu Zhang:** Visualization, Investigation. **Lumeng Xie:** Investigation, Software. **Shiqiang Zhao:** Investigation, Data curation. **Ying Liu:** Software, Validation. **Zhenming Zhang:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the Fundamental Research Funds for the Central Universities (2021BLRD09).

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