Effects of Ecological Ditch and Wetland in Reducing Farmland Drainage Pollutants in Hetao Irrigation District

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Abstract [**Objectives**] To explore the control mode of farmland drainage pollutants and investigate the effects of ecological ditch and wetland on reducing farmland drainage pollutants in Hetao Irrigation District. [**Methods**] Based on the demonstration construction project of the ecological ditch-constructed wetland system in the Hetao Irrigation District, an experimental study was conducted from July to September 2023 to investigate the interception and purification effects of ecological ditches, constructed wetlands, and the combined ecological ditch-constructed wetland system on farmland drainage pollutants. Key water quality parameters measured included total nitrogen (TN) concentration and total phosphorus (TP) concentration. [**Results**] Different treatment modes of ecological ditches and constructed wetlands have a certain removal effect on nitrogen and phosphorus pollutants in water bodies. The ecological ditches treated with *Astragalus laxmannii*, *Melilotus officinalis*, *Medicago sativa*, bio-ball substrate, and bio-sheet substrate showed reduction efficiencies for TN and TP of 21.09% and 23.84%, 12.06% and 26.67%, 20.08% and 34.15%, 23.65% and 20.56%, and 19.92% and 25.83%, respectively. The emergent plant area showed reduction efficiencies of 24.28% for TN and 17.89% for TP, while the submerged plant area achieved a reduction efficiency of 10.21% for both TN and TP. Among the different treatment modes, the ecological ditch with *M. sativa* performed better in TP removal, whereas the bio-ball substrate treatment mode showed higher effectiveness in TN removal. In addition, the emergent plant area exhibited better TP removal performance, while the submerged plant area was more effective in TN removal. The combined system of ecological ditch and constructed wetland achieved removal rates of 37.55% for TN and 11.47% for TP. It effectively facilitates the step-by-step interception and adsorption purification of pollutants, thereby showing significant removal and purification effects on nitrogen and phosphorus contaminants. This contributes to mitigating agricultural non-point source pollution. [**Conclusions**] The combined ecological ditch-constructed wetland system serves dual functions of agricultural drainage and pollutant interception and purification. It reduces the pollution load of farmland drainage on receiving water bodies to some extent and mitigates agricultural non-point source pollution. Therefore, it is a relatively suitable technology for managing agricultural non-point source pollution in the Hetao Irrigation District.

Key words Ecological ditch, Constructed wetland, Pollutant, Purification effect, Hetao Irrigation District

0 Introduction

The ecological ditch and constructed wetland system is an ecosystem designed based on ecological principles, leveraging material and energy exchanges among the "atmosphere, water, soil, and organisms" to achieve water purification as well as pollutant interception and reduction. Both domestic and international experts and scholars have focused on studying the pollutant interception efficiency of ecological ditches and constructed wetland systems from various perspectives. Research has primarily been conducted through methods such as laboratory-scale model experiments, field prototype trials, and numerical simulations. Studies have covered aspects including the structural design of ecological ditches, the establishment of plant communities in constructed wetlands, the pollutant interception and purification effectiveness of ecological ditches and wetlands, as well as plant configuration and microbial functions in these systems. These efforts have yielded substantial research outcomes[1-4]. Existing research has shown that ecological ditches and constructed wetlands demonstrate effective interception and purification of pollutants. These systems can efficiently remove and purify contaminants from water bodies through various mechanisms, including sediment adsorption, plant uptake, and microbial degradation[5-6]. However, the relationships and contributions of the treatment mechanisms in ecological ditch and constructed wetland systems under different operational modes still require in-depth investigation. Particularly for specific irrigation districts, further field prototype experiments are needed to select vegetation with strong adaptability, broad applicability, and effective pollutant removal performance. Therefore, conducting research on the pollutant reduction effects of ecological ditch and constructed wetland systems in treating agricultural drainage remains of significant importance.

As one of China's important grain production bases, the Hetao Irrigation District in Inner Mongolia has long faced the issue of agricultural non-point source pollution, which cannot be overlooked. The use of chemical fertilizers and pesticides, while contributing to increased agricultural yields, has also led to elevated levels of nutrients such as nitrogen and phosphorus in farmland

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drainage. These pollutants eventually flow into Lake Ulansuhai, causing water quality deterioration and degradation of the aquatic ecosystem[7]. As essential parts of the farmland ecosystem in the Hetao Irrigation District, drainage ditches and wetlands serve as critical pathways for agricultural drainage. Besides, they can intercept and purify pollutants through mechanisms such as sediment adsorption, plant uptake, and microbial degradation[8-9]. Therefore, promoting the ecological functions and value of farmland drainage ditches and wetlands in the Hetao Irrigation District, and constructing an ecological ditch-constructed wetland system to intercept and purify pollutants, has become an effective approach to alleviate agricultural non-point source pollution in the irrigation area. Based on the actual conditions of the graded drainage system and extensive engineering coverage in the farmland drainage ditches of the Hetao Irrigation District, we proposed engineering modifications to traditional earthen ditches to form ecological ditches. By constructing an ecological interception system composed of ecological ditches and constructed wetlands, we performed experimental research to assess the reduction effects on pollutants such as nitrogen and phosphorus. It is intended to explore new approaches for preventing and controlling agricultural non-point source pollution in the Hetao Irrigation District while providing theoretical support for water environment management in the Ulansuhai Lake Basin.

1 Materials and methods

1.1 Overview of the test area The test area is located in the Linhe Yellow River National Wetland Park (107°24′ E, 40°41′ N) within the Hetao Irrigation District, Bayannur City, Inner Mongolia Autonomous Region, as shown in Fig. 1. The area features representative climatic, soil, and water-salt conditions. The terrain is predominantly plain, characterized by a mid-temperate continental semi-arid climate. It experiences scarce rainfall but strong evaporation. Precipitation exhibits distinct seasonal variation and uneven annual distribution, with the rainy season concentrated in July and August, accounting for 70% to 80% of the annual total. The multi-year average precipitation ranges from 130 to 285 mm, while the multi-year average annual evaporation ranges from 2 030 to 3 180 mm. The region enjoys ample sunshine, with a multi-year average temperature between 3.7 and 7.6 ℃. The groundwater level remains between 0.5 and 1 m throughout the year. The soil is slightly alkaline and moderately saline[10].

1.2 Construction of test system This test system was constructed to simulate the structure and functions of farmland drainage ditches and natural wetland systems. It primarily consists of an ecological ditch and a constructed wetland. The system has been built and undergone initial operation. Its structure remains intact with no frost heave damage observed, meeting the requirements for engineering durability. In addition, it integrates multiple functions, including drainage and desalination, sediment adsorption, plant uptake, and microbial degradation. The system is now ready for field-scale prototype testing. A schematic diagram of the test setting is shown in Fig. 2.

Fig. 1 Location of test area

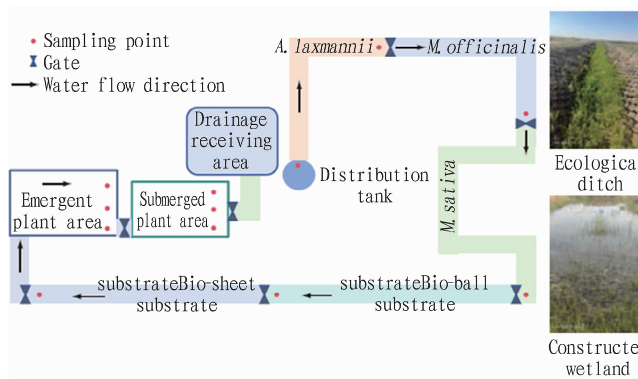

Fig. 2 Test system

The ecological ditch was constructed by retrofitting an existing earthen drainage ditch. Its cross-sectional structural design followed the *Design Standard for Irrigation and Drainage Engineering* (GB 50288-2018). For slope protection, a novel plant-engineering composite technology was employed. This involved laying polypropylene filament geotextile and polymer honeycomb geocells on the compacted slopes and bottom of the ditch. This composite structure effectively serves multiple functions, including drainage, isolation, reinforcement, protection, filtration, and cushioning. The plants cultivated in the ecological ditch are selected based on experimental research considering the soil, climate, and water quality conditions of the Hetao Irrigation District. The chosen species are salt-tolerant, easy to establish, and effective in absorbing pollutants such as nitrogen and phosphorus. To achieve flow velocity control and drainage measurement, control structures were added to the drainage ditch, with broad-crested weirs and vertical sluice gates installed at certain intervals along the channel. Based on the actual field terrain, the drainage ditch was arranged laterally and designed with a trapezoidal cross-section. The total length of the ditch is 540 m, divided into 5 sections, each serving as a distinct experimental treatment. The ditch has a top width of 3.2 m, a bottom width of 1 m, a depth of 0.95 m, and a controlled water depth ranging from 0.5 to 0.6 m.

The constructed wetland area comprises an emergent plant area of 1 000 m^2 and a submerged plant area of 360 m^2. It is a surface-flow constructed wetland with a total construction area of 1 360 m^2 and a total thickness of 0.6 m. The system consists of a containment and impermeable structure, engineered substrate, and aquatic plants. The impermeable layer is constructed using a new impermeable material, TPO. The substrate filtration media is laid in two layers: the surface layer is a soil layer with a thickness of 0.4 m, and the bottom layer is a gravel layer with a thickness of 0.2 m. Based on the climatic, soil, and water quality conditions of the Hetao Irrigation District, and considering plant survival rate, the emergent plant area was planted with a reasonable combination of species such as *Scirpus validus*, *Iris* spp., *Typha* spp., *Schoenoplectus triqueter*, and *Phragmites australis*. The planting density was 10 – 12 plants/m^2, using the seedling transplanting method. The submerged plant area was planted with a mix of *Myriophyllum spicatum*, *Hydrilla verticillata*, and floating-leaved plants such as *Nelumbo nucifera*, at a density of 20 – 30 plants/m^2 using the cutting method.

1.3 Test design Based on preliminary indoor experimental results and considering the actual field growth conditions of vegetation in the Hetao Irrigation District, different processing modes were applied to the ecological ditch and the constructed wetland within the test system. A total of eight different processing modes were established, including blank control, *A. laxmannii*, *M. officinalis*, *M. sativa*, bio-ball substrate, bio-sheet substrate, emergent plant area, and submerged plant area (Table 1).

Table 1 Settings of processing modes

Mode No.	Type	Characteristics	Sample point code
1	Natural ditch	The natural earthen ditch, which was not processed during the test, served as a blank control.	CK
2	Ecological ditch	*Astragalus laxmannii*, a perennial herbaceous plant of the Fabaceae family, was planted in the ditch.	XJ
3	Ecological ditch	*Melilotus officinalis*, an erect biennial herb of the Fabaceae family, was planted in the ditch.	HH
4	Ecological ditch	*Medicago sativa*, a perennial herbaceous plant of the Fabaceae family, was planted in the ditch.	ZH
5	Ecological ditch	No vegetation was planted in the ditch. Instead, bio-ball substrate material (porous suspended ball fillers composed of polyethylene, polypropylene, activated carbon, *etc.*) was used.	SQ
6	Ecological ditch	No vegetation was planted in the ditch. Instead, bio-sheet substrate material (plastic discs composed of aldehyde fiber, plastic rope, *etc.*) was used.	SP
7	Constructed wetland	Emergent plant area	TS
8	Constructed wetland	Submerged plant area	CS

The test area is located in the field, with no surrounding farmland drainage and a lack of artificial rainfall facilities, so the field prototype test used self-prepared solution as the test water supply source. Based on the drainage water quality monitoring data of the Hetao Irrigation District from 2010 to 2021, potassium dihydrogen phosphate (KH_2PO_4), ammonium bicarbonate (NH_4HCO_3), and glucose ($C_6H_{12}O_6$) were added to the mixing tank before the test to prepare a solution, simulating the nitrogen and phosphorus pollutant concentrations in farmland drainage of the Hetao Irrigation District. The prepared water concentrations for the test were TN: 4 – 5 mg/L and TP: 0.3 – 0.5 mg/L. We carried out the field test from July to September 2023 and consisted of two phases. In the first phase, after the ecological ditch-constructed wetland system was filled with water and began operation, the gates were closed to keep the different processing modes relatively isolated, allowing the water within the system to remain static. This phase aimed to investigate the interception and reduction efficiency of pollutants under different treatment conditions in the ecological ditch-constructed wetland system. Considering the flood tolerance duration of the plants, sampling was conducted at 12-h intervals. Overlying water and sediment samples were collected from the ecological ditch and the constructed wetland under different processing modes at 0, 12, 24, 36, 48, 60, 72, and 84 h, respectively. In the second phase, after the ecological ditch-constructed wetland system was refilled and put into operation, the gates were not closed, allowing the water to flow within the system. This phase aimed to investigate the interception and reduction efficiency of pollutants under the combined operation of the ecological ditch-constructed wetland system. Considering the plants' tolerance to inundation and the limitations of the test water supply conditions, sampling was conducted at intervals of 6 h. Overlying water and sediment were sampled from different processing modes in the ecological ditch-constructed wetland system at 0, 6, 12, and 18 h, respectively.

1.4 Sampling and detection For this test, overlying water was sourced from undisturbed ditch water, sampled at 0.5 times the water depth, with 150 mL collected per sampling point. Sediment (200 g) from the ditch was placed in a polyethylene bag and then transferred to a polyethylene centrifuge tube, followed by centrifugation at 3 000 r/min for 20 min. The supernatant was filtered through a 0.45 μm membrane to obtain interstitial water samples. TN and TP in both the overlying water and sediment interstitial water were analyzed. TN concentration was determined via alkaline potassium persulfate digestion UV spectrophotometry, while TP concentration was measured using molybdenum-antimony anti-spectrophotometry. Other routine water quality parameters were assessed with a handheld YSI multi-parameter water quality analyzer[11].

1.5 Data analysis To investigate the removal efficiency of nitrogen and phosphorus pollutants by the ecological ditch and constructed wetland systems, we used the following formula to calculate the reduction efficiency (R_t) of nitrogen and phosphorus pollutants for either the ecological ditch or the constructed wetland:

$$R_t = (C_t - C_0)/C_0 \times 100\%$$

where R_t is the reduction efficiency of nitrogen and phosphorus pollutants by the ecological ditch or constructed wetland over time t; C_t is the concentration of nitrogen and phosphorus pollutants in the overlying water of the ecological ditch or constructed wetland at time t, expressed in mg/L; C_0 is the initial concentration of nitrogen and phosphorus pollutants in the overlying water immediately after the ecological ditch or constructed wetland began operating with impounded water.

2 Results and analysis

2.1 Analysis of nitrogen and phosphorus reduction efficiency of vegetation At 0, 12, 24, 36, 48, 60, 72, and 84 h after the ecological ditch-constructed wetland system began operating with the sluice gate closed, overlying water and sediment samples were collected from the ecological ditch under different vegetation conditions. The variations in TN and TP concentrations were measured, and the reduction efficiencies of nitrogen and phosphorus by different vegetation types were calculated. The results are shown in Fig. 3 and Table 2. As the test progressed, after being intercepted and purified by the ecological ditch, the TN and TP concentrations in the overlying water under different vegetation conditions all showed a declining trend. The pollutant concentrations decreased notably during the initial stage of the experiment and then gradually leveled off. In contrast, the TN and TP concentrations in the sediment interstitial water exhibited an increasing trend, with the rate of increase gradually slowing down over time. After 84 h of the test, in the ecological ditch planted with *A. laxmannii*, the TN concentration in the overlying water decreased from 4.79 to 3.78 mg/L, and the TP concentration decreased from 0.430 to 0.329 mg/L. The reduction efficiencies for TN and TP were 21.09% and 23.84%, respectively. In the ecological ditch planted with *M. officinalis*, the TN concentration in the overlying water decreased from 4.31 to 3.79 mg/L, and the TP concentration decreased from 0.390 to 0.290 mg/L, with reduction efficiencies of 12.06% and 26.67% for TN and TP, respectively. In the ecological ditch planted with *M. sativa*, the TN concentration in the overlying water decreased from 4.83 to 3.86 mg/L, and the TP concentration decreased from 0.410 to 0.270 mg/L, resulting in reduction efficiencies of 20.08% and 34.15% for TN and TP, respectively.

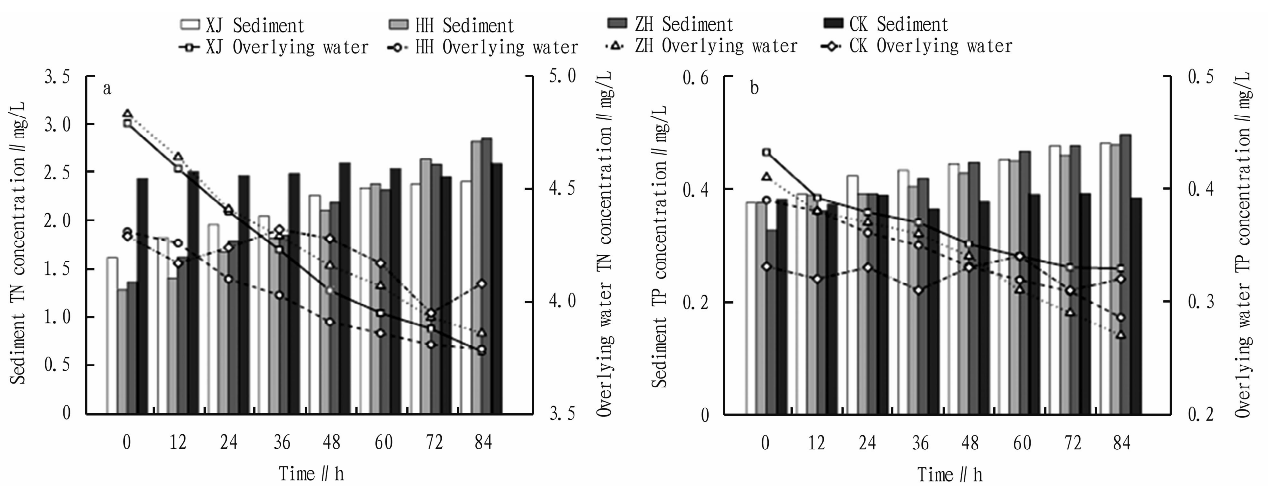

Fig. 3 Changes of nitrogen and phosphorus concentrations in ecological drainage ditches treated with vegetation

Table 2 Nitrogen and phosphorus reduction efficiency of ecological drainage ditches treated with vegetation

Ecological ditch mode	TN concentration change // mg/L	TN reduction efficiency // %	TP concentration change // mg/L	TP reduction efficiency // %
Astragalus laxmannii	1.01	21.09	0.103	23.84
Melilotus officinalis	0.52	12.06	0.104	26.67
Medicago sativa	0.97	20.08	0.140	34.15

Compared with natural earthen drainage ditches, ecological ditches planted with vegetation demonstrate a pronounced removal effect on pollutants in water. During the test, a concentration gradient of nitrogen and phosphorus formed between the overlying water and the sediment interstitial water within the ecological ditch, facilitating the transfer of nitrogen and phosphorus from the overlying water into the sediment interstitial water. In addition, the sediment in the ecological ditch provided physical interception and adsorption, retaining pollutants from the overlying water and causing them to deposit into the sediment. The oxygen transfer from vegetation in the ecological ditch results in higher dissolved oxygen levels, thereby improving the microbial environment in the sediment. This leads to greater microbial abundance and diversity compared to natural earthen drainage ditches, ultimately enhancing the adsorption and purification of pollutants from the overlying water[12]. Furthermore, vegetation growing in the ecological ditch can effectively adsorb and intercept particulate phosphorus in the water through its root systems. Under suitable conditions, anaerobic and aerobic microorganisms drive nitrification and denitrification processes, enabling the effective removal of organic nitrogen from the water. Through physical interception, plant uptake, and microbial activity, the overlying water can be efficiently purified in terms of TN and TP[13].

2.2 Analysis of nitrogen and phosphorus reduction efficiency of substrate materials At 0, 12, 24, 36, 48, 60, 72, and 84 h after the ecological ditch-constructed wetland system began operating with the sluice gate closed, overlying water and sediment samples were collected from ecological ditches containing different substrate materials. The variations in TN and TP concentrations were measured, and the reduction efficiencies of nitrogen and phosphorus by different substrate materials were calculated. The results are shown in Fig. 4 and Table 3.

As the test progressed, following the interception and purification by the ecological ditch, the TN and TP concentrations in the overlying water under different substrate material conditions showed a distinct decreasing trend. In contrast, the TN and TP concentrations in the sediment interstitial water exhibited an increasing trend, with the rate of increase gradually leveling off. After 84 h of testing, in the bio-ball substrate ecological ditch, the TN concentration in the overlying water decreased from 4.82 to 3.68 mg/L, and the TP concentration decreased from 0.460 to 0.365 mg/L, resulting in reduction efficiencies of 23.65% for TN and 20.56% for TP. In the bio-sheet substrate ecological ditch, the TN concentration decreased from 4.72 to 3.78 mg/L, and the TP concentration decreased from 0.480 to 0.356 mg/L, corresponding to reduction efficiencies of 19.92% for TN and 25.83% for TP.

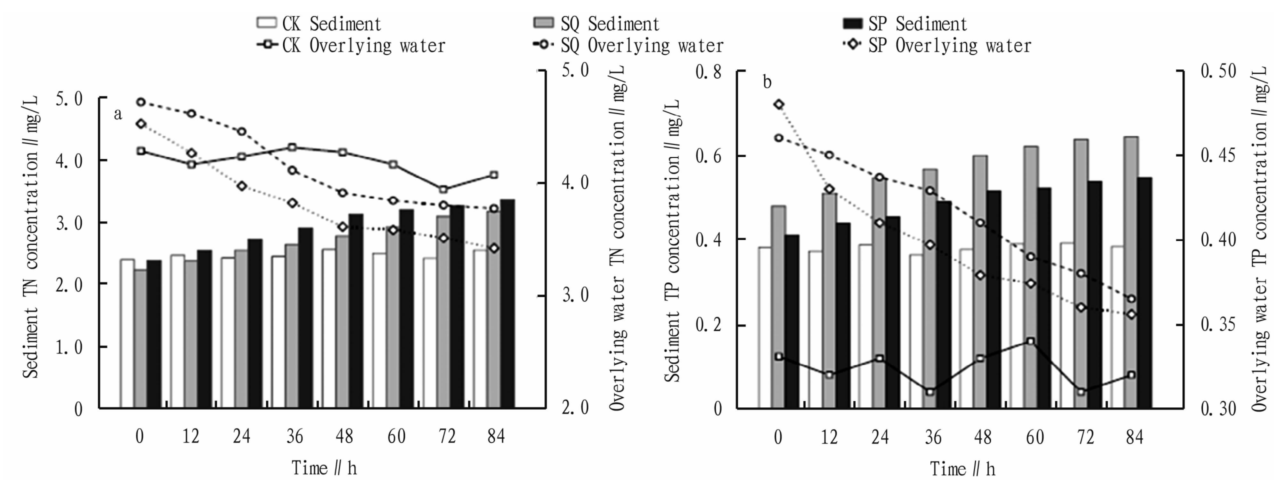

Fig. 4 Changes of nitrogen and phosphorus concentration in ecological drainage ditch treated with substrate materials

Table 3 Nitrogen and phosphorus reduction efficiency of ecological drainage ditch treated with substrate materials

Ecological ditch mode	TN concentration // mg/L	TN reduction efficiency // %	TP concentration // mg/L	TP reduction efficiency // %
Bio-ball substrate	1.14	23.65	0.095	20.65
Bio-sheet substrate	0.94	19.92	0.124	25.83

Compared with natural earthen drainage ditches, ecological ditches utilizing bio-ball substrate and bio-sheet substrate demonstrate significant pollutant removal. The substrate materials, consisting of porous suspended balls and plastic ropes, feature abundant pores and skeletal structures, providing a large specific surface area. This offers a favorable environment for microbial attachment, growth, and proliferation. The microorganisms attached to the substrate materials possess nutrient absorption and purification capabilities, effectively removing nitrogen and phosphorus pollutants from the overlying water[14]. Simultaneously, the bio-ball and bio-sheet substrate materials can, to some extent, reduce the flow velocity within the ditch channel, increase the contact area with the water body, and prolong the hydraulic retention time. Besides, the substrate materials themselves exhibit certain adsorption properties, thereby further enhancing the adsorption and removal of nitrogen and phosphorus pollutants from the overlying water[15].

2.3 Analysis of nitrogen and phosphorus reduction efficiencies of constructed wetland At 0, 12, 24, 36, 48, 60, 72, and 84 h after the ecological ditch constructed wetland system began operating with the sluice gate closed, overlying water and sediment samples were collected from different constructed wetlands respectively. The variations in TN and TP concentrations were measured, and the reduction efficiencies of nitrogen and phosphorus by the constructed wetlands were calculated. The results are shown in Fig. 5 and Table 4. As the test progressed, after being intercepted and purified by the constructed wetland, the TN and TP concentrations in the overlying water both exhibited a declining trend, with the decrease being relatively pronounced. In contrast, the TN and TP concentrations in the sediment interstitial water showed an increasing trend, and the rate of increase gradually slowed down. After 84 h of testing, in the emergent plant area, the TN concentration in the overlying water decreased from 4.53 to 3.43 mg/L, and the TP concentration decreased from 0.872 to 0.716 mg/L. The reduction efficiencies for TN and TP were 24.28% and 17.89%, respectively. In the submerged plant area, the TN concentration in the overlying water decreased from 4.06 to 2.97 mg/L, and the TP concentration decreased from 0.901 to 0.809 mg/L, resulting in reduction efficiencies of 26.85% for TN and 10.21% for TP.

Table 4 Reduction efficiency of nitrogen and phosphorus in constructed wetlands

Constructed wetland modes	TN concentration // mg/L	TN reduction efficiency // %	TP concentration // mg/L	TP reduction efficiency // %
Emergent plant area	1.10	24.28	0.156	17.89
Submerged plant area	1.09	26.85	0.092	10.21

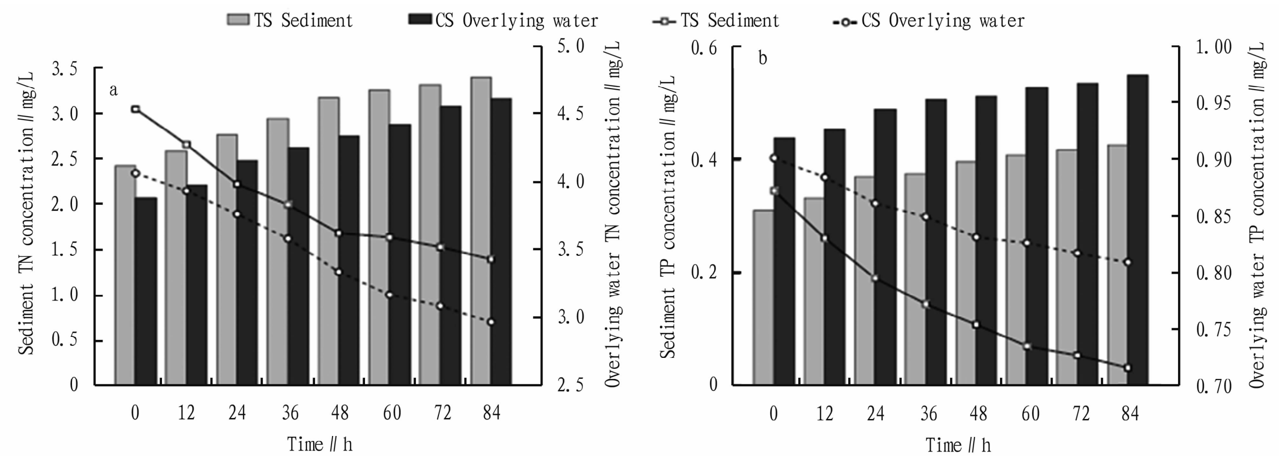

Fig. 5 Changes of nitrogen and phosphorus concentration in constructed wetland

The constructed wetland system exhibits a certain capacity for reducing and purifying nitrogen and phosphorus pollutants. Submerged plants, which need to be immersed in water, release oxygen generated through photosynthesis into the water. This effectively increases the dissolved oxygen content in the water body, thereby inhibiting the survival of anaerobic bacteria, preventing water deterioration, and protecting the ecological balance of the aquatic environment. Besides, submerged plants can also absorb nitrogen and phosphorus pollutants from the sediment or water through their root systems. In contrast, emergent plants have their roots anchored in the sediment while their stems and leaves extend above the water surface. Their substantial biomass and high nitrogen and phosphorus accumulation capacity facilitate the uptake of these elements from the water. In addition, emergent plants can accumulate non degradable pollutants within their tissues. Subsequent harvesting of the plants completely removes these pollutants from the water body, thereby achieving effective pollutant removal[16]. Moreover, the substrate layer in the constructed wetland system also promotes the growth and reproduction of microorganisms, thereby enhancing microbial removal of nitrogen and phosphorus. The plants in the constructed wetland system absorb and accumulate nitrogen and phosphorus pollutants. Furthermore, the photosynthesis and respiration of plants during growth stimulate microbial activity within the wetland, which further influences the removal efficiency of nitrogen and phosphorus contaminants[17].

2.4 Analysis of nitrogen and phosphorus reduction efficiencies of ecological ditch-constructed wetland system After the ecological ditch constructed wetland system was refilled and operated with the sluice gate left open, allowing water to flow continuously through the system, and considering the flooding tolerance of the plants and the limitations of the experimental water supply, overlying water and sediment samples were collected under different treatment conditions within the system at 0, 6, 12, and 18 h. The changes in TN and TP concentrations were measured, and the results are shown in Fig. 6. At the initial time of 0 h in the test, the concentrations in the emergent plant area and submerged plant area of the ecological ditch and constructed wetland under different treatment conditions showed little difference and fluctuated. Over time, after being intercepted and purified by the ecological ditch constructed wetland system, both TN and TP concentrations exhibited a decreasing trend, with a notable decline observed after 18 h. Specifically, the TN concentration in the overlying water decreased from 2.69 to 1.48 mg/L, and the TP concentration decreased from 0.947 to 0.741 mg/L, indicating that the ecological ditch constructed wetland system had a significant reduction effect on TN and TP. In contrast, the concentrations of TN and TP in the sediment interstitial water displayed an increasing trend, with the rate of increase gradually leveling off. Specifically, the TN concentration in the sediment interstitial water rose from 0.435 to 0.552 mg/L, and the TP concentration increased from 0.515 to 0.616 mg/L, demonstrating that the sediment in the ecological ditch constructed wetland system possessed a certain adsorption and deposition capacity for TN and TP[18].

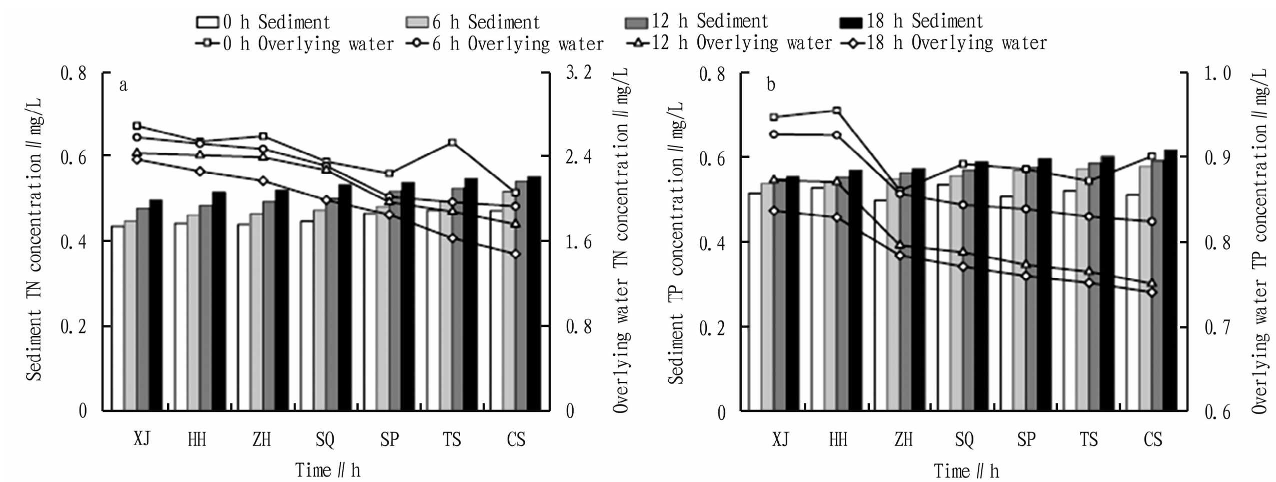

Fig. 6 Changes of pollutant concentration in the combined system of ecological drainage ditch and constructed wetland

We calculated the reduction efficiency of nitrogen and phosphorus in the ecological ditch-constructed wetland system, and the results are shown in Table 5. After 18 h of test, the removal rates of TN and TP by the ecological ditch-constructed wetland system were 37.55% and 11.47%, respectively, showing the characteristic of TN > TP in purification effect. The removal rates of TN at 0, 6, 12, and 18 h were 23.42%, 25.19%, 27.57%, and 37.55%, respectively, showing an increasing trend in removal efficiency; the removal rates of TP at 0, 6, 12, and 18 h were 4.86%, 11.11%, 13.97%, and 11.47%, respectively, showing a trend of first increasing and then decreasing; the removal effect of TP by the ecological ditch-constructed wetland system showed some fluctuation, while the interception and purification effect on TN was better and more stable, primarily due to the fact that phosphorus mainly exists in particulate and adsorbed forms, which are affected by water flow during field tests, and phosphorus deposited in the sediment is prone to re-release into the overlying water, thereby affecting the purification effect of TP[19-20].

Table 5 Nitrogen and phosphorus reduction efficiency of the combined system of ecological drainage ditch and constructed wetland

Time // h	TN concentration // mg/L	TN reduction efficiency // %	TP concentration // mg/L	TP reduction efficiency // %
0	0.63	23.42	0.046	4.86
6	0.62	25.91	0.103	11.11
12	0.67	27.57	0.122	13.97
18	0.89	37.55	0.096	11.47

3 Conclusions

The farmland drainage ditch system in the Hetao Irrigation District is extensive and numerous but lacks ecological design. Frost heave damage to earthen drainage ditches often leads to slope collapse and siltation. In addition, severe soil salinization in the irrigation district has resulted in few experimental studies on the interception and purification of farmland drainage pollutants using the ecological ditch-constructed wetland system in the Hetao Irrigation District. Based on the ecological modification of traditional earthen drainage ditches in the Hetao Irrigation District, this study constructed an ecological ditch-constructed wetland system and, for the first time, conducted test on pollutant reduction, interception, and purification tailored to the farmland drainage conditions of the Hetao Irrigation District. We reached the following conclusions:

(i) Compared with natural earthen drainage ditches, ecological ditches with different processing modes exhibit certain pollutant removal effects on water bodies. The reduction efficiencies of TN and TP for ecological ditches treated with *A. laxmannii*, *M. officinalis*, *M. sativa*, bio-ball substrate, and bio-sheet substrate are 21.09% and 23.84%, 12.06% and 26.67%, 20.08% and 34.15%, 23.65% and 20.56%, and 19.92% and 25.83%, respectively. Among them, the ecological ditch with the *M. sativa* processing mode shows better TP removal performance, while the ecological ditch with the bio-ball substrate processing mode demonstrates better TN removal performance.

(ii) Constructed wetlands of different modes exhibit certain removal and purification effects on nitrogen and phosphorus pollutants, with varying degrees of effectiveness. The reduction efficiencies for TN and TP in the emergent plant area are 24.28% and 17.89%, respectively, while those in the submerged plant area are 26.85% and 10.21%, respectively. The emergent plant area demonstrates better removal performance for TP, whereas the submerged plant area shows better removal performance for TN.

(iii) The removal rates of TN and TP by the ecological ditch-constructed wetland system are 37.55% and 11.47%, respectively, showing effective removal and purification effects on nitrogen and phosphorus pollutants. The combined ecological ditch-constructed wetland system serves dual functions of agricultural drainage and pollutant interception and purification. It reduces the pollution load of farmland drainage on receiving water bodies to some extent and mitigates agricultural non-point source pollution. Therefore, it is a relatively suitable technology for managing agricultural non-point source pollution in the Hetao Irrigation District.

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