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Seasonal Dynamics of Nitrogen and Phosphorus in Water and Sediment of A Multi-level Ditch System in Sanjiang Plain, Northeast China

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Abstract: The multi-level ditch system developed in the Sanjiang Plain, Northeast China has sped up water drainage process hence transferred more pollutants from farmlands into the rivers of this region. Understanding the seasonal dynamics of nitrogen (N) and phosphorus (P) transportation in the ditch system and the role of different ditch size is thus crucial for water pollution control of the rivers in the Sanjiang Plain. In this study, an investigation was conducted in the Nongjiang watershed of the Sanjiang Plain to study the nutrient variation and the correlation between water and sediments in the ditch system in terms of ditch level. Water and sediments samples were collected in each ditch level in growing season at regular intervals (once per month), and TN, NO_3^--N, NH_4^+-N, TP, and PO_4^{3-}-P were analyzed. The results show that nutrient contents in water were higher in June and July, especially in July, the contents of TN and TP were 3.21 mg/L and 0.84 mg/L in field ditch, 4.04 mg/L and 1.06 mg/L in lateral ditch, 2.46 mg/L and 0.70 mg/L in branch ditch, 1.92 mg/L and 0.63 mg/L in main ditch, respectively. In August and September, the nutrient contents in the water were relatively lower. The peak value of nutrient in ditch water had been moving from the field ditch to the main ditch over time, showing a remarkable impact of ditch system on river water environment. The nutrient transfer in ditch sediments could only be found in rainfall season. Nutrient contents in ditch sediment had effect on that in ditch water, but nutrients in ditch water and sediments had different origination. Ditch management in terms of the key factors is hence very important for protecting river water environment.

Keywords: multi-level ditch system; nitrogen; phosphorus; spatio-temporal variation; drainage water; sediment

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1 Introduction

Agricultural drainage ditch is important for crop production in poorly drained wetlands by removing surface and ground water through speeding up water flow process, so it has been developed in many regions throughout the world. The drainage ditch system is not only effective in transporting water, but also an important pathway for nutrients, particularly nitrogen (N) and phosphorus (P) and other contaminants, such as pesticides from farmlands flowing into adjacent water bodies (Kladivko *et al*., 1999; Tomer *et al*., 2003).

Non-point source pollution has been identified as a key reason in water quality deterioration around the world (Carpenter *et al*., 1998; Davis and Koop, 2006). Ditch system provides a unique opportunity to address the non-point source pollution problem due to high concentration of the contaminants from agriculture and the engineered nature of ditches. Behrendt and Bachor (1998) predicted that 47% of N and 12% of P emissioned from the federal state Mecklenburg-Vorpommern (North-Eastern Germany) to the Baltic Sea originated

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from tile drainage. Ditch water quality is determined by watershed land use and management such as farmland area and fertilizer application (Wang *et al*., 2005). Zhang *et al*. (2004) found that the concentrations of N and P were generally higher in the ditches on vegetable farms than in citrus groves because of the different fertilizing rates. Jia *et al*. (2006) estimated that drainage control in paddy field may reduce subsurface discharge up to 94% through field ditch. Ditch water quality is also influenced by the seasonal changes of rainfall, water flow speed, water retention time, vegetation of ditch, and so on (Smith and Pappsa, 2007; Sharpley *et al*., 2007; Strock *et al*., 2007). Ditches can alternate between being a sink and a source for dissolved inorganic P and particulate P concentrations throughout the year (Kroger *et al*., 2008).

Well-managed ditch system can function as nature wetlands in mitigating nutrient load of surface water body through a variety of biochemical processes in nutrient retention of farmland drainage (Gilliam and Skaggs, 1986; Hill, 1996; Needelman *et al*., 2007; Strock *et al*., 2007). Because drainage ditches can serve as valuable habitats for various organisms (Van *et al*., 1991; Meuleman *et al*., 1993; Crum *et al*., 1998). However, the effect of ditch size (level) on nutrient transfer from agricultural drainage has not been highlighted (Herzon and Helenius, 2008).

The non-point source pollution of the Sanjiang Plain, Northeast China is a matter of great concern due to its agricultural development (Lu *et al*., 2008). The main way of agricultural development in the Sanjiang Plain was to dig ditches to drain out water so that the wetlands can be cultivated. The drainage ditches form a multi-level network of corridors and become main pathways for pollutants transporting from farmland to river, which has been a serious impact on regional water environment and wetland ecosystems (Lu *et al*., 2007b). Being a channel of drainage water and a connection of farmland and river, ditch system plays a key role in non-point source pollution of the water environment in this region. It has been identified that ditch water pollution mainly results from agricultural drainage (Zhang *et al*., 2004; Wang *et al*., 2005; Jia *et al*., 2006) and ditch sediments (Kroger *et al*., 2008), and is remarkably influenced by rainfall and ditch vegetation (Zhang *et al*., 2004; Sharpley *et al*., 2007; Smith and Pappsa, 2007; Strock *et al*., 2007). However, little attention has been paid to the nutrients transportation in the multi-level ditch system and the role of different-size ditches, and the relationship of the nutrients in water and sediments in the multi-level ditches throughout growing season in the Sanjiang Plain. Understanding the role of different-size ditches and the ditch system as a whole in nutrient transportation is crucial for protecting water environment and wetland ecosystems of the study area, and it would be significant to the sustainable development of the agriculture.

2 Materials and Methods

2.1 Study area

The Sanjiang Plain is located in the northeastern part of Heilongjiang Province, Northeast China (43°49′55″–48°27′40″N, 129°11′20″–135°05′26″E) with the temperate humid continental monsoon climate. The frost-free period is 130–145 d with annual precipitation of 450–700 mm.

The study area is located in the northeast of the Sanjiang Plain (46°49′42″–48°13′58″N, 132°31′26″–134°22′26″E). The area, covering about 11 000 km^2, is consisted of 15 large farms, and remote from urban areas. The mean annual temperature is 1–2℃, the annual precipitation is in the range of 500–600 mm, and 60%–70% of the precipitation is concentrated in the growing season.

In the study area, reclamation through ditching wetlands is the predominant form of agricultural exploitation (Zhang *et al*., 2010), and a multi-level ditch system has been developed during the exploitation. The agricultural land use in the study area is of two main types, paddy field and upland crops, where rice and soybean are the dominant crops. Different fertilizers, including N fertilizer (urea and ammonium bicarbonate) and P fertilizer (ammonium hydrogen phosphate), are currently used for cropping, and they can enter the water environment alongside water drainage process through the ditch system. It is one of the main factors which cause the river environment deterioration in the study area.

In this study, a multi-level ditch system was selected in connection with the Nongjiang River, and the Nongjiang ditch system belongs to the Nongjiang basin in the Sanjiang Plain. Drainage ditches are referred to those structures, already within the agricultural landscape, and become a conduit for water flow between farmland and a receiving water body (river). The multi-level ditch system is composed of four levels of ditches (Fig. 1), that is, field ditch, lateral ditch, branch ditch and main ditch (Xi and Lu, 2007). The width of the four level ditches varies greatly, and the size of ditch gradually increases from lower level (field ditch and lateral ditch) to higher level (branch ditch and main ditch). It is 1 m for field ditch, 3 m for lateral ditch, 7 m for branch ditch, and 13 m for main ditch. The water of farmland drainage flows from the field ditch to the main ditch. The dominant species in different-level ditch were surveyed. The vegetation covers in the field ditch and the lateral ditch were higher than those in the branch ditch and the main ditch by visual inspection (Table 1).

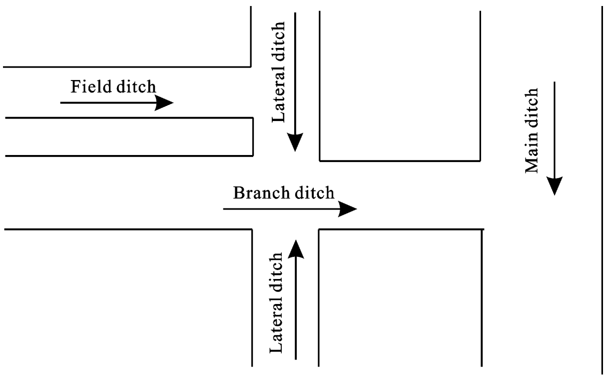


Fig. 1 Flow direction and frame diagram of multi-level ditch system in Sanjiang Plain

Table 1 Vegetation characteristics of multi-level ditch system

Ditch level	Dominant plant species	Coverage (%)
Field ditch	Reed	1–5
Lateral ditch	Cattail, reed	10–30
Branch ditch	Scirpus tabernaemontani	5–10
Main ditch	Cattail, Scirpus tabernaemontani	5–8

2.2 Sampling method

The survey was conducted from June to September in 2007 in the growing season of rice, and the monthly rainfalls in study period were 49.6 mm, 12.7 mm, 293.3 mm, and 31.1 mm respectively from June to September. The distribution of daily rainfall was different in every month. Twice in June the rainfall was 10–30 mm, and in other days almost zero; twice in July was 2–5 mm, and in other days without rainfall; in August, in three days was 10–20 mm, in two days was 20–30 mm, one was 40–50 mm, one was 80–90 mm, and in other days was 0–10 mm; and in September in three days was 5–10 mm, and in other days was 0–5 mm. Therefore, the weather kept dry in June and July, much rainfall concentrated in August. It would help to analyze the effects of ditch system on N and P concentrations.

The water and sediments samples of the ditch system were collected according to ditch level, and three sample sites in the outset, middle and outlet of every ditch level were selected. From middle June to middle September at regular intervals (once per month), at each sampling site, water samples were collected in mid-depth of water, and sediments samples were collected at the bottom of ditch (0–20 cm). Triplicate water and sediments samples were collected in each site, then the water samples were taken to laboratory and stored in a refrigerator at 4℃, and the sediment were purified to remove impurities, air-dried, passed through 80 mesh sieve before analysis.

2.3 Analytical methods

The samples were analyzed for pH, electrical conductivity (EC), total nitrogen (TN), total phosphorus (TP), NO_3^--N, NH_4^+-N and PO_4^{3-}-P. For water samples, the pH and EC were detected using pH/conductivity meter (HORIBA U-10, Japan) in the sites. The TN was determined by using potassium sulpersulphate oxidation-ultraviolet spectrophotometry, and TP by ammonium molybdate spectrophotometry (SEPA, 2002). The NO_3^--N and NH_4^+-N were measured with an ion chromatograph (ICS-90, USA), and PO_4^{3-}-P by the molybdenum-blue method (SEPA, 2002). For the sediments, pH was measured at a soil-to-water ratio of 1∶5 with pH-meter (HI 99121, China). The measurement of TN was conducted by semimicro-kjeldahl method, the TP by Mo-Sb antispetrophotography method, PO_4^{3-}-P by ammonium chloride extraction colorimetic method, NH_4^+-N by Nessler's reagent colorimetry, and NO_3^--N by phenol disulfonic acid spectriphotometric method (Lu, 1999).

2.4 Statistical analysis

One-way ANOVA for all the data and Spearman correlation for water and sediments correlation were performed using SPSS 11.5.

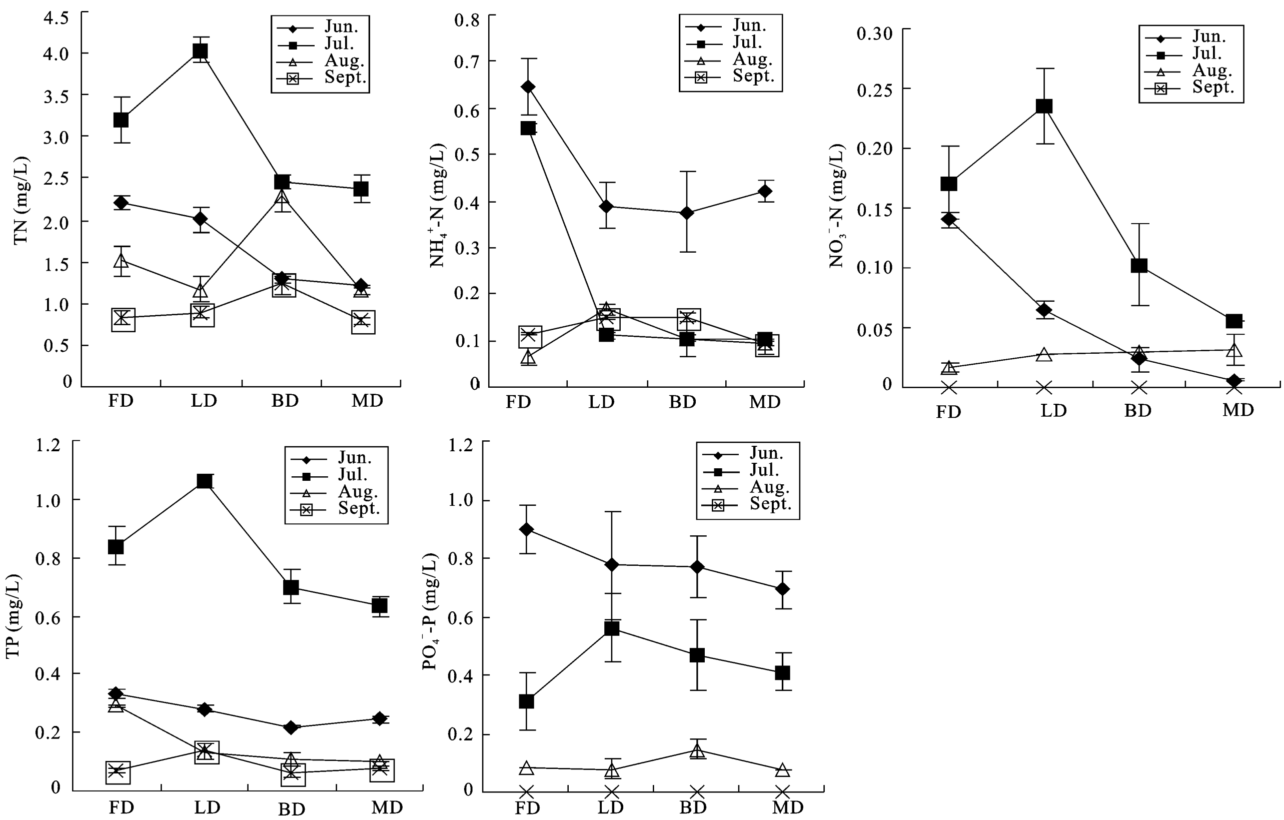
3 Results and Analyses

3.1 Spatio-temporal variation of nutrients in ditch water

The concentration of nutrients in water varied with ditch level and time along the ditch system (Fig. 2). Other than we expected that all nutrients would decrease from low to high ditch levels, the peak concentrations transferred over time along the ditch system in growing season and varied for different nutrient elements. For example, the highest concentration of TN occurred in the field ditch in June, the lateral ditch in July, and the branch ditch in August and September. The variation of the peak value for other nutrients was different. Generally, NO_3^--N was easy to transfer compared with NH_4^+-N in the ditch system because the peak value of NH_4^+-N concentration was only shown in the lateral ditch.

The concentrations of TN and TP in ditch water were generally higher in July than that in other months, and they were the lowest in August and September with rainy season coming. The concentrations of TN and TP in the water were relatively high in the field ditch in June, indicating that agricultural drainage in May was the main factor that caused water pollution of ditch.

The results of ANOVA analysis are shown in Table 2 and Table 3. Rainfall in different months had significant difference during the research period. There was no farmland drainage as a result of dry weather and very little rainfall in June and July, and velocity of flow in ditch water was slow. The situation in August and September was quite opposite. Therefore, the impacts of ditch level on N and P concentrations were well reflected by comparing the difference of N and P concentrations in different ditch level in the two periods (June and July; August and September). The N concentrations between the low-level ditch (field ditch and lateral ditch)



FD: field ditch; LD: lateral ditch; BD: branch ditch; MD: main ditch

Fig. 2 Spatio-temporal variation of mean nutrient concentration in water of multi-level ditch system

Table 2 Differences of nutrient concentrations in water among different ditch levels in June and July

Ditch level	TN (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	TP (mg/L)	PO_4^{3-}-P (mg/L)
Field ditch	2.87 ± 0.31 ab	0.64 ± 0.059 a	0.15 ± 0.014 a	0.58 ± 0.11 a	0.062 ± 0.014 a
Lateral ditch	3.20 ± 0.53 a	0.35 ± 0.028 b	0.15 ± 0.040 a	0.67 ± 0.17 a	0.063 ± 0.011 a
Branch ditch	1.93 ± 0.29 b	0.30 ± 0.057 b	0.078 ± 0.019 b	0.46 ± 0.10 a	0.063 ± 0.010 a
Main ditch	1.88 ± 0.25 b	0.29 ± 0.046 b	0.084 ± 0.0020 b	0.47 ± 0.089 a	0.060 ± 0.0048 a

Note: Different letters after the values indicate a significant difference ($p < 0.05$) among different ditch levels and the high-level ditch (branch ditch and main ditch) were significantly different in the two periods of slow water velocity (June and July) and fast water velocity (August and September). The difference of P concentrations was not significant in all the cases.

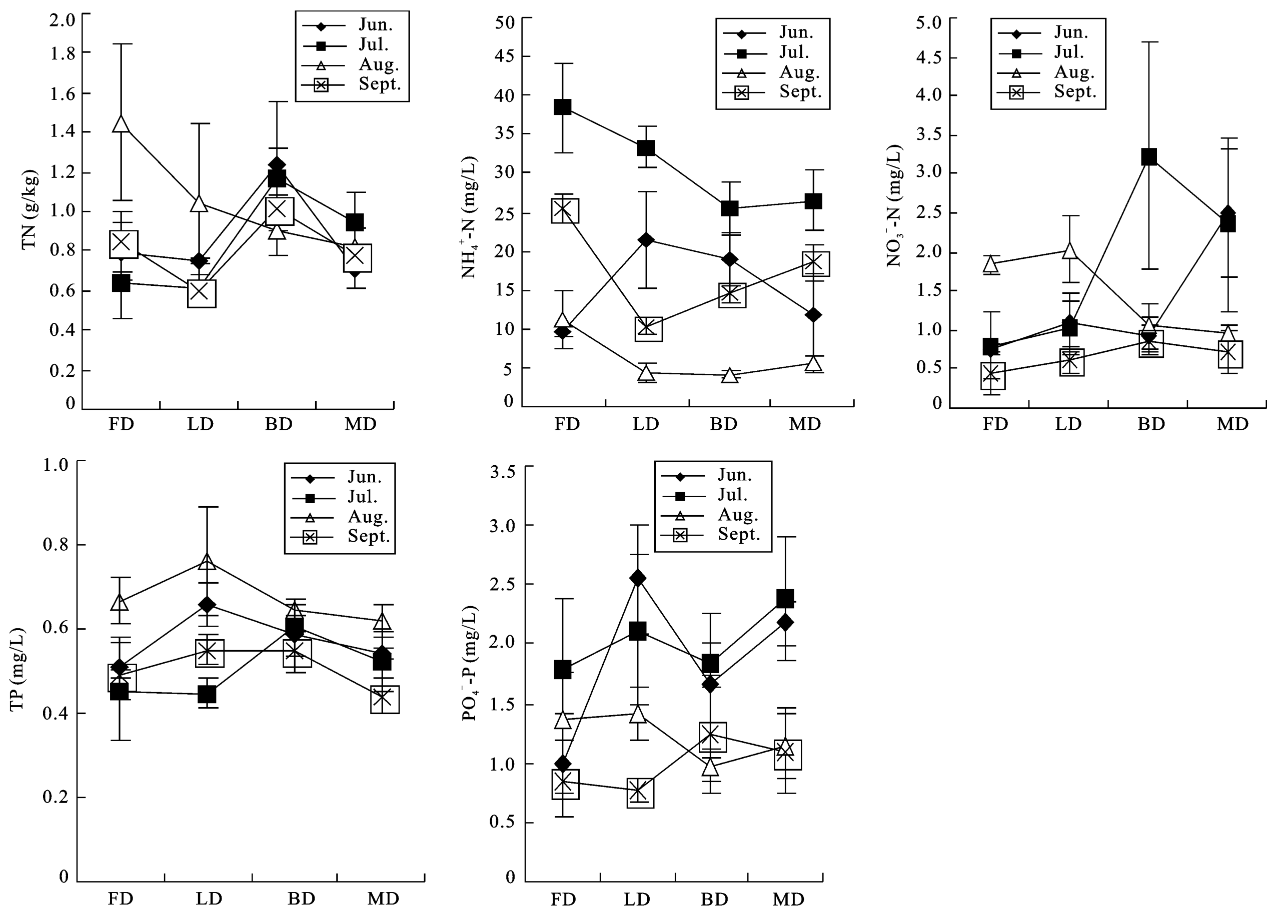
3.2 Spatio-temporal variation of nutrients in ditch sediments

The dissolved nutrients in ditch sediments changed greatly as NH_4^+-N from 4.19 mg/kg to 53.19 mg/kg, NO_3^--N from 0.44 mg/kg to 3.23 mg/kg, and PO_4^{3-}-P from 7.73 mg/kg to 25.47 mg/kg. The variation of concentrations along the ditch system was similar in June and July, and changed obviously in August, and then decreased in September (Fig. 3). It was also not as expected as high in low-level (field ditch, lateral ditch) and low in high-level (branch ditch, main ditch) throughout growing season. For the concentration of nutrients in the sediments, the peak concentrations along the ditch system did not transfer over time, which was different from the concentrations change in the water, and the result in this study is also different from that in the

Table 3 Differences of nutrient concentrations in water among different ditch levels in August and September

Ditch level	TN (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	TP (mg/L)	PO_4^{3-}-P (mg/L)
Field ditch	1.11 ± 0.15 ab	0.077 ± 0.0091 b	0.0083 ± 0.0040 a	0.14 ± 0.037 a	0.0050 ± 0.0022 a
Lateral ditch	1.59 ± 0.32 a	0.16 ± 0.0057 a	0.015 ± 0.0067 a	0.13 ± 0.017 a	0.0033 ± 0.0021 a
Branch ditch	1.17 ± 0.10 ab	0.13 ± 0.020 a	0.015 ± 0.0067 a	0.087 ± 0.018 a	0.0067 ± 0.0033 a
Main ditch	1.00 ± 0.11 b	0.12 ± 0.014 a	0.017 ± 0.0095 a	0.12 ± 0.016 a	0.0050 ± 0.0022 a

Note: Different letters after the values indicate a significant difference ($p < 0.05$) among different ditch levels



FD: field ditch; LD: lateral ditch; BD: branch ditch; MD: main ditch

Fig. 3 Spatio-temporal variation of mean nutrient concentration in sediments of multi-level ditch system previous study for the study area (Lu *et al.*, 2007a).

The results of ANOVA analysis show that the concentrations of N and P at different ditch level had no significant difference regardless of ditch water speed (p < 0.05) (Tables 4 and Table 5).

3.3 Correlation of nutrient concentrations in water and sediment

The results of Spearman correlation analysis show that the concentration of TN in the water was significantly correlated with those of NH_4^+-N and PO_4^{3-}-P in the sediment (Table 6). The concentration of NO_3^--N in the water was significantly positively correlated with those of NH_4^+-N and PO_4^{3-}-P and negatively correlated with that of TP in the sediment. PO_4^{3-}-P concentration in the water was significantly positively correlated with PO_4^{3-}-P concentration in the sediment. The concentration of TP in the water was significantly positively correlated with those of NH_4^+-N and PO_4^{3-}-P in the sediment. The concentrations of N and P in the sediment had effect on those in the water.

4 Discussion

4.1 Effect of agricultural management, rainfall and ditch property on nutrient dynamics in water

Agricultural drainage is the main source of ditch water pollution (Zhang *et al.*, 2004), and it is supported by the results in this study. The concentration of N and P in water was higher in low level ditch (the field and lateral ditch) with little rainfall in June and July (no drainage) as a result of drainage of rice paddy field in May. Rainfall can greatly influence ditch water quality through modifying hydrological process (Zhang *et al.*, 2004). The rainfall between months is quite different in the study area. There is no farmland drainage as a result of dry weather and a little rainfall in June and July, the flow velocity of ditch water is slow. However, the situa-

Table 4 Differences of nutrient concentrations in sediments among different ditch levels in June and July

Ditch level	TN (g/kg)	NO_3^--N (mg/kg)	NH_4^+-N (mg/kg)	TP (g/kg)	PO_4^{3-}-P (mg/kg)
Field ditch	0.71 ± 0.10 b	0.78 ± 0.19 a	24.01 ± 6.91 a	0.48 ± 0.062 a	13.90 ± 3.74 a
Lateral ditch	0.68 ± 0.040 b	1.07 ± 0.22 a	27.43 ± 3.99 a	0.55 ± 0.054 a	23.33 ± 3.58 a
Branch ditch	1.21 ± 0.18 a	1.93 ± 0.72 a	21.80 ± 2.58 a	0.60 ± 0.046 a	17.23 ± 3.30 a
Main ditch	0.84 ± 0.094 b	2.41 ± 0.67 a	20.02 ± 3.62 a	0.53 ± 0.039 a	22.87 ± 2.87 a

Note: Different letters after the values indicate a significant difference (p < 0.05) among different ditch levels

Table 5 Differences of nutrient concentrations in sediments among different ditch levels in August and September

Ditch level	TN (g/kg)	NO_3^--N (mg/kg)	NH_4^+-N (mg/kg)	TP (g/kg)	PO_4^{3-}-P (mg/kg)
Field ditch	1.15 ± 0.23 a	1.14 ± 0.33 a	18.37 ± 3.65 a	0.58 ± 0.046 a	10.97 ± 2.16 a
Lateral ditch	0.81 ± 0.20 a	1.30 ± 0.38 a	7.37 ± 1.51 b	0.66 ± 0.076 a	10.93 ± 1.81 a
Branch ditch	0.96 ± 0.070 a	0.96 ± 0.16 a	9.32 ± 2.36 b	0.60 ± 0.031 a	11.10 ± 2.35 a
Main ditch	0.80 ± 0.055 a	0.84 ± 0.14 a	11.98 ± 3.15 ab	0.53 ± 0.047 a	11.17 ± 2.01 a

Note: Different letters after the values indicate a significant difference (p < 0.05) among different ditch levels

Table 6 Correlation coefficients between nutrients in water and sediment

	TN	NO_3^--N	NH_4^+-N	TP	PO_4^{3-}-P	pH	EC
TN	–0.092	0.126	0.498*	–0.170	0.344*	–0.682*	–0.078
NO_3^--N	–0.176	0.035	0.444*	–0.312*	0.350*	–0.501*	–0.024
NH_4^+-N	–0.179	–0.037	0.096	–0.162	0.179	–0.015	0.028
TP	–0.135	0.163	0.580*	–0.252	0.386*	–0.620*	0.017
PO_4^{3-}-P	–0.087	0.206	0.209	0.019	0.439*	0.127	0.206
pH	–0.142	–0.010	0.061	–0.324*	–0.195	–0.074	–0.082
EC	0.081	0.283*	0.254	–0.098	0.243	–0.091	0.291*

Notes: *, p < 0.05; the first row shows the parameters of sediment, and the left column shows the parameters of water tion is quite opposite in August and September with much rainfall. Therefore, the concentrations of N and P in ditch water were lower in August and September than those in June and July because of rainfall dilution. Alongside water flow, the peak value of N was also transferred from low level ditch to high level ditch, though NO_3^--N was easy to transfer compared with NH_4^+-N because of the absorption effect of soil particle and colloid on NH_4^+-N. Rainfall dilution may be the dominant element to affect nutrient transfer at this time compared with other factors such as plant uptake, soil adsorption, *etc*. Therefore, the impact of ditch level on the distribution of N and P can be well reflected by comparing them in the two periods of time (June and July; August and September) when rainfall obviously changed.

Ditch property can also greatly affect water quality in terms of ditch structure, vegetation and microorganisms (Ma *et al*., 2005). The plant uptake, soil adsorption and microbial biochemical well take effect as water in ditch flow slowly (Wang *et al*., 2007). In this study, nitrogen concentrations were significantly different between the low level ditch and the high one in June and July, which might reflect the impact of these factors. In all the cases, phosphorus concentrations in ditch water were not significantly different, and the reason may be the strong soil sorption and limited plant uptake because of low vegetation coverage (Table 1) (Lantzke *et al*., 1998; Luederitz *et al*., 2001). Low concentration of PO_4^{3-}-P may be the reason that phosphorus in agricultural drainage mainly exists in the form of particulate (Xu *et al*., 2007).

For ditch system, the spatio-temporal variation of nutrient content in water can provide some guidance to non-point source pollution control. At the end of agricultural drainage in late May, the concentrations of TN and TP in ditch system are higher. With a little rainfall and no drainage in June and July, N and P mainly concentrate in the lower level ditch, thus they can be partly removed in the ditch system by improving ditch vegetation. In August and September, the concentrations of N and P are lower in ditch system, and it may be related to more water quantity. The water can be diverted into adjacent meadow (degraded from wetlands) to restore wetlands and to purify the water in the wetlands (Zhang *et al*., 2010).

4.2 Contribution of sediments to water nutrient dynamics in ditch system

Ditches can alternate between being a sink and a source of water pollutants throughout the year (Kroger *et al*., 2008), and ditch sediments play a distinct role. In this study, the concentrations of TN and TP in water were generally higher in July (no drainage and a little rainfall), indicating that ditch sediment release may also contribute to the concentrations of N and P in ditch water in addition to agricultural drainage.

One direct reason may be that the source of N and P in the sediment in ditch is different from that in the water (Zhai *et al*., 2008). The sources of N and P in the sediment may mainly come from vegetation debris and organism activities (Jiang *et al*., 2005). The TN in the surface sediment of ditch decomposes and transforms quickly and greatly with the time (Jiang *et al*., 2005), and it can transform into ammonium nitrogen and desorbed into ditch water, so ammonium nitrogen in the sediments has significant correlation with nitrogen content in the water (Table 6).

Correlation of pH in sediment with nitrogen concentration in the water may be an indirect reason. NH_4^+-N turns into ammonia when pH in sediment becomes higher, and H^+ in the water can also compete with NH_4^+-N in soil adsorption point with low pH so as to promote its desorption (Xi *et al*., 2007). Soil with both negative charge and the positive charge can absorb anion such as PO_4^{3-}-P and NO_3^--N, and much PO_4^{3-}-P can promote NO_3^--N desorption according to competition of absorption point, so PO_4^{3-}-P has significantly positive correlation with NO_3^--N in ditch water.

Another reason for nutrient concentrations in the sediment were different from that in the water may be that sediment transportation is mainly an event process occurring with peak flow (Quilbe *et al*., 2006). In the study period, the limited rainfall and minimal inputs from agricultural drainage resulted in great reduction in water quantity and velocities in June and July, which reduced sediments transportation during this period. Therefore, the concentration of N and P at different ditch level had no significant difference, and variation tendency of N and P in the sediment in the ditch system was generally similar. While in August and September with much rainfall and fast water velocity, no significant difference of nutrient contents in sediments between the different ditch levels has been found.

5 Conclusions

Nutrients in water and sediment vary in the multi-level ditch system of the Sanjiang Plain, Northeast China. In the ditch water, the form of N and P is dominated by particulate, and the peak values of nutrients concentrations transferred over time along the ditch system in growing season under the driving of agricultural drainage and rainfalls. The nutrients concentrations in the ditch sediment are higher in August, and the transfer mainly occurs in rainfall season. Nutrient concentrations in the ditch water are determined by the sources of agricultural drainage and the release of ditch sediment in June and July, and are reduced by dilution function when rainfall season coming in August. The ditch system is not only a channel of drainage water, but also a source of water pollutants, therefore, ditch management in terms of the key factors is important for protecting water environment in the study area, and the further study on the impact of different land use patterns on N and P concentrations of ditch system is needed.

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