The Effects of Disturbance on the Release of Nitrogen and Phosphorus from Sediment in Rural Ditches

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ABSTRACT

Reduced nitrogen (N) and phosphorus (P) released from sediments in rural areas pose a significant challenge to residential sewage treatment and management. Under different disturbance velocities, simulation experiments were undertaken to investigate the effect of disturbance on the release of N and P from rural ditch sediments into the water at the water-sediment interface. No significant difference in the release characteristics of N and P was found among different disturbance velocities. The release fluxes of TN and NH_4^+-N in the non-disturbance water body were significantly higher than in the disturbance water body, which suggests that increasing water flow influences the release of TN and NH_4^+-N from sediment into the water. The release fluxes of TP and PO_4^{3-}-P were significantly lower in non-disturbance than the disturbance water body, which suggested that disturbance increased the release of TP and PO_4^{3-}-P in sediments. For both disturbance and non-disturbance conditions, TN and NH_4^+-N in the sediment were rapidly released into the water body at 0-10 days, and TP and PO_4^{3-}-P steadily rose in the disturbance water body until stabilizing after 20 days. TN, NH_4^+-N, TP, and PO_4^{3-}-P concentrations all had a negative correlation with DO, and the correlations between TN and NH_4^+-N were substantial. The percentages of a certain N or P speciation fraction in sediments did not alter between disturbance and non-disturbance conditions, implying that disturbance had no effect on N or P speciation.

INTRODUCTION

The cycle of nitrogen (N) and phosphorus (P) in nature is of critical importance because they are essential nutrient elements in the ecosystem. However, excessive N and P can cause serious ecological problems. Due to the extensive application of fertilizers (Howarth 2004) and discharge of domestic water, a large amount of N and P is released into natural water (Isermann 1990, Zhu et al. 2018), leading to the eutrophication of rivers and lakes. Sediment plays an important role in regulating the nutrient content in the water body environment (Meade 1982, Span et al. 1990).

Numerous studies have shown that the absorption and desorption of N and P in the water-sediment interface are affected by multiple factors, such as temperature, pH, the concentration of organic matter, and hydraulic disturbance (Rzepecki 2010, Zhang et al. 2012). Therefore, nutrient release characteristics in river and lake sediment have received extensive attention (Rozan et al. 2002), and various simulation experiments under controlled conditions have been developed to elucidate the mechanism underlying nutrient release (Geng et al. 2020, Luo & Lu 2020, Wang et al. 2008, Yiping et al. 2004). Previous studies, on the other hand, have focused on sediments in rivers and lakes, with less attention paid to sediment in rural areas due to the difficulty of home sewage treatment and management caused by scattering. Because of the population disparity, sediments in rural ditches are affected by water flow, and the effects of disturbance on nitrogen and phosphorus release in rural sediment are unknown.

In this study, disturbed simulation experiments were used to explore the release characteristics of N and P in the water-sediment interface and their effect on the different disturbance velocities of N and P concentrations of rural ditch sediment into the water. This study provides fundamental information for sewage management and environmental protection in rural areas.

MATERIALS AND METHODS

Sediment Collection and Preparation

Trial sediment samples were collected from a rural ditch in Xiaokanglang Village, Kunming City, Yunnan Province, China. Approximately 112 kg of sediments were collected at a depth of 0-3 cm. The sample was returned to the laboratory to

determine the N and P release characteristics of the sediment. Sediment particle size (PS), N, and P background contents are listed in Table 1. According to Canadian environmental quality guidelines (CEQGs), total nitrogen (TN, 6.15 g.kg^{-1}) and total phosphorus (TP, 5.91 g.kg^{-1}) in sediments exceeded the threshold effect concentrations (TN, 2 g·kg^{-1}; TP, 4.8 g·kg^{-1}) for toxic biological effects, which indicated that N and P have potential ecological risks, and their potential ecological risk assessment is needed for extended discussion.

Batch Disturbance Experiments

The collected ditch sediments were placed into five pre-designed and manufactured rectangle polyvinyl chloride sinks (sink 1) with a width and height of 16 cm to a length of 1000 cm (Fig. 1). Approximately 7.5 kg of the sediments were mixed to an average depth of 3 cm and then allowed to stand for 24 h. Distilled water (15 L) was introduced into each water sink 2, covered with a water pump, and the water flow velocities were adjusted to 5, 15, 30, and 60 L.h^{-1} using a float flowmeter. Water was then circularly injected into sink 1 from sink 2 by a water pump (Risheng, RS-468B). At the setting times, approximately 20 mL of the water samples were collected from the water body in sink 2, and 1.5 g of sediment samples were collected from surface sediment in sink 1. The samples were collected at five-day intervals until day 30. Distilled water was added to the original scale of sink 2 after the water sample was collected. Moreover, 15L of distilled water was added to water sink 1 in a non-disturbance experiment. 20 mL of water samples and 1.5 g of sediment samples were taken from sink 1.

The water samples were immediately filtered, and the pH, dissolved oxygen (DO), oxidation-reduction potential (Eh), and electric conductivity (EC) in the water were determined (HACH-HQ40d). Total nitrogen (TN), total phosphorus (TP),

and orthophosphorus (PO$_4$$^{3-}$-P) in the water were determined by potassium persulfate oxidation-UV spectrophotometry, and ammonia (NH$_4$$^+$-N) was determined by Nessler's reagent spectrophotometry (Wang & Wu 2016). Each sample was evaluated three times, and the results are presented as average values. The nitrogen in all the sediment samples was fractionated as ion-exchanged form nitrogen (IEF-N), weak acid extractable form nitrogen (WAEF-N), strong alkaline extractable form nitrogen (SAEF-N), and strong oxidant extractable form nitrogen (SOEF-N), and phosphorus was fractionated as labile phosphorus (Labile-P), reducible soluble phosphorus (RSP), iron- and aluminum-bound phosphorus (Fe/Al-P), and calcium-bound phosphorus (Ca-P), according to the sequential extraction method (Wang & Wu 2016).

The release flux (R) of nitrogen and phosphorus in sediments was calculated using the following equation:

$$R = [V(C_n - C_0) + \sum_{j=1}^{n} V_t(C_{j-1} - C_a)]/At \quad ...(1)$$

where R(mg.(m^2·d)$^{-1}$) is the release flux, V(L) is the water volume, C_0, C_n, and C_{j-1} (mg.L^{-1}) are the concentrations of nutrients in the water body in the starting sampling, the nth and j-1th sampling, C_a (mg.L^{-1}) is the nutrient concentration of the added water sample, V_t (L) is the sampling volume, A is the water-sediment contact interface (m^2), and t is release time (d).

Statistical Analysis

The statistical differences in pH, DO, Eh, EC, TN, and TP contents between disturbance and non-disturbance water from each collection time were determined using the paired t-test, with statistical significance defined as p ≤ 0.05. The association between nutritional species concentrations and pH, DO, Eh, and EC content was investigated using bivariate
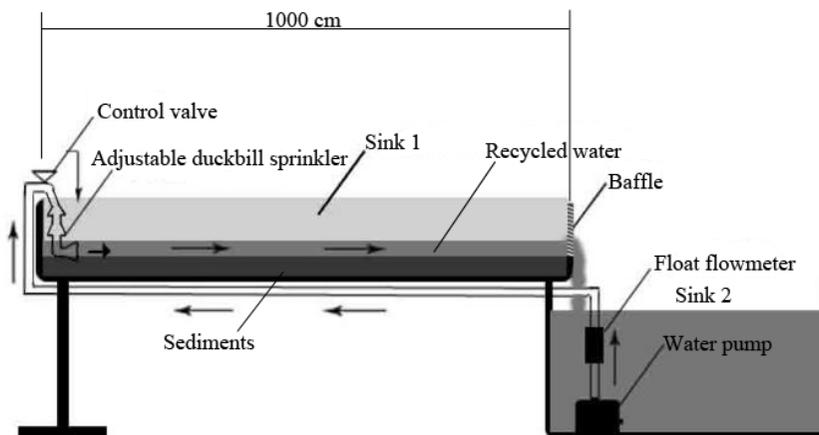
Fig. 1: Simulation device for the release experiment.

Table 1: Basic properties of the sediment.

PS (µm)			Nitrogen contents (g.kg⁻¹)					Phosphorus contents (g.kg⁻¹)				
<2	2~20	20~2000	TN	IEF-N	WAEF-N	SAEF-N	SOEF-N	TP	Labile-P	RSP	Fe/Al-P	Ca-P
0.0%	72. 5%	27.5%	6.15	0.78	1.14	0.30	3.34	5.91	0.59	0.57	0.92	3.12

IEF-N: ion-exchanged form nitrogen; WAEF-N: weak acid extractable form nitrogen; SAEF-N: strong alkaline extractable form nitrogen; SOEF-N: strong oxidant extractable form nitrogen;

Labile-P: labile phosphorus; RSP: reducible soluble phosphorus;

Fe/Al-P: iron and aluminum-bound phosphorus; Ca-P: calcium-bound phosphorus

correlation in a two-tailed test, with statistical significance defined as $p \leq 0.05$. SPSS22.0 software was used for all statistical analyses.

RESULTS AND DISCUSSION

pH, DO, Eh and EC

The overall pH, DO, Eh, and EC contents of disturbance and non-disturbance water bodies are summarized in Table 2. The pH, DO, Eh, and EC values of non-disturbance water were 8.53, 3.86 (g.kg⁻¹), 97.51 (mV), and 707.14 (µs.cm⁻¹), respectively. The paired *t*-test showed no remarkable differences in the pH, Eh, and EC between disturbance and non-disturbance water (p>0.05). DO contents were significantly higher in disturbance water than non-disturbance water (p<0.05), and their contents slightly increased with disturbance velocity (0-60 L.h⁻¹). Due to the increased surface of water interaction with air, this finding demonstrated that disturbance could enhance DO levels in contrast to non-disturbance. For the same disturbance velocity owing to oxygen in the water for consumption by microorganisms, DO contents steadily dropped with time (0-10 days), and DO contents stabilized after 10 days (Beutel 2006).

Release Characteristics of N in Disturbance and Non-Disturbance Water bodies

The release dynamics of TN and NH_4^+-N in the sediments from water bodies with different disturbance velocities are shown in Fig. 2. The concentrations of TN and NH_4^+-N in

disturbance and non-disturbance water bodies gradually increased and then gradually decreased and stabilized. The maximum concentrations of TN and NH_4^+-N in the disturbance water body were all observed at day 10, and the maximum concentrations of TN and NH_4^+-N in the non-disturbance water body were found at day 20. Similar results have been reported in which TN and NO_3^--N in the sediment pore water were generally released into the water body during the first 10 days (Chen et al. 2020). In the early stage (0-10 days) of the experiment, there was a concentration difference between TN and NH_4^+-N at the water-sediment interface, resulting in a quick release of NH_4^+-N, NO_3^--N, and inorganic salt nitrogen in the sediment into the water body and, thus, a rapid increase in the TN and NH_4^+-N concentrations in the water body (Zhu et al. 2018). It has been shown that the oxygen content in the water is sufficient, the aerobic microorganisms grow rapidly, and the organic matter released from the sediment is quickly decomposed to NH_3 (Beutel 2006).

From days 0 to 10, there were no noticeable differences in TN, NH_4^+-N concentrations between disturbance and non-disturbance water bodies, however, from days 10 to 30, the non-disturbance water body had greater TN, NH_4^+-N concentrations than the disturbance water body. This result indicated that disturbance of the water body did not increase the release of TN and NH_4^+-N from bottom sediments into the water body, which might be related to nitrogen adsorption by suspended particulate matter in the water body caused by disturbance. This phenomenon was found in the water-sed-

Table 2: The pH, DO, Eh and EC values and the concentrations of N and P in disturbance and non-disturbance water samples.

DV (L.h⁻¹)	pH (H₂O)	DO (g.kg⁻¹)	Eh (mV)	EC (µs.cm⁻¹)	Nutrients concentration (g.kg⁻¹)			
					TN	NH₄⁺-N	TP	PO₄³⁻-P
0	8.53±0.19	3.86±2.70	97.51±66.15	707.14±240.27	18.23±9.02	13.48±6.87	0.40±0.20	0.03±0.02
5	8.61±0.08	6.36±1.18	98.17±42.46	696.95±182.22	9.10±6.51	6.25±6.48	0.88±0.48	0.30±0.19
15	8.63±0.12	6.54±1.32	98.00±51.82	701.81±182.88	7.30±5.49	4.67±5.00	0.93±0.46	0.33±0.20
30	8.70±0.15	6.71±1.27	100.25±53.71	696.29±192.16	5.75±4.37	4.62±4.85	0.87±0.43	0.31±0.18
60	8.64±0.23	6.99±1.04	100.69±57.37	631.38±146.42	8.43±7.24	5.83±6.29	0.77±0.39	0.26±0.18

DV: Disturbance velocity (L.h⁻¹); 0: non-disturbance water; 5-60: disturbance water.
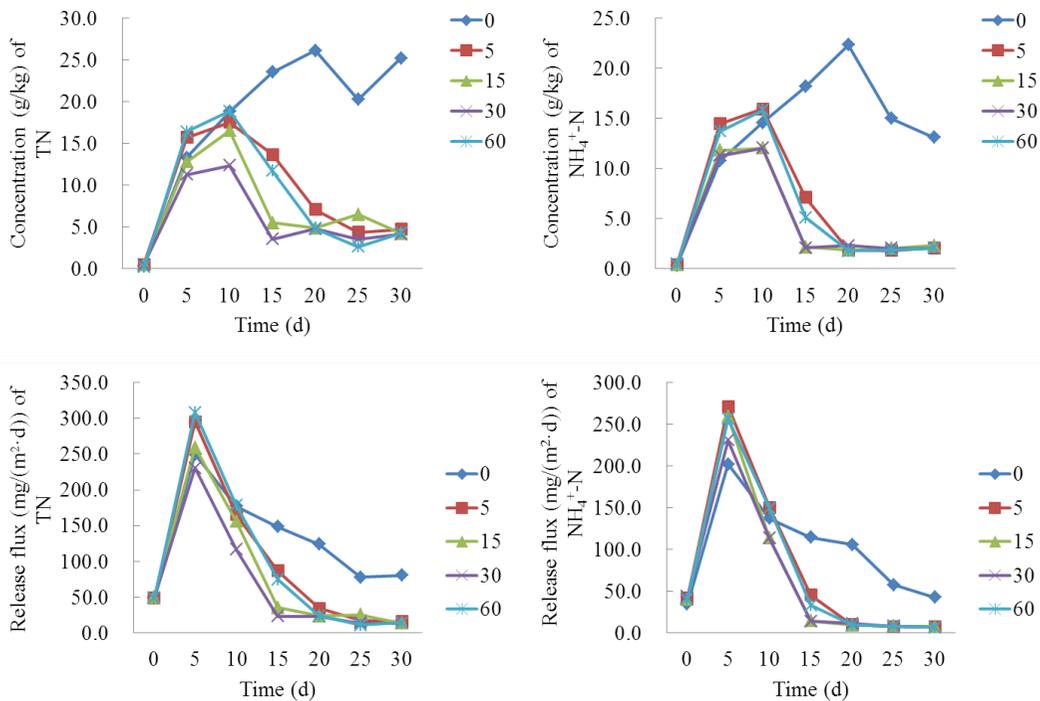
Fig. 2: Release concentrations and fluxes of TN and NH_4^+-N in disturbance and non-disturbance water bodies. The 0 represents the concentrations in the non-disturbance water body; the 5-60 represent concentrations in the disturbance water body.

iment interface from Poyang and Dongting Lake, where influences of variable disturbance velocity on ammonium nitrogen and nitrate nitrogen concentrations of the overlying water in the sediment-water interface were not obvious (Ni et al. 2020, Tong et al. 2016).

The release fluxes of TN and NH_4^+-N in different disturbance and non-disturbance water bodies are listed in Fig. 2. For disturbance and non-disturbance conditions, the release fluxes of TN and NH_4^+-N reached the highest levels at 5 days and subsequently, gradually declined. The highest TN release fluxes of 0, 5, 15, 30, and 60 L.h^{-1} were 249.91, 295.23, 259.19, 230.69, and 307.84 mg.(m^2·d)$^{-1}$, and the highest NH_4^+-N release fluxes of 0, 5, 15, 30, and 60 L.h^{-1} were 202.12, 271.06, 259.18, 230.68, and 256.81 mg.(m^2·d)$^{-1}$, respectively. The release fluxes of TN, NH_4^+-N were higher in the non-disturbance than the disturbance water body after 10 days. This result revealed an effect of increasing water flow on TN and NH_4^+-N release from sediment into water that was not obvious. The release flux of nitrogen was related to nitrogen morphological characteristics, physical and chemical properties of the sediment, microbial activities, and external environmental factors (Domagalski et al. 2007). The same trend was found for release fluxes of TN and NH_4^+-N for different disturbance velocities.

Release Characteristics of P in Disturbance and Non-Disturbance Water bodies

The concentrations of TP and PO_4^{3-}-P gradually increased in the disturbance water body and then basically stabilized after 20 days (Fig. 3). The concentrations of TP gradually increased in the non-disturbance water body, and the PO_4^{3-}-P concentrations were relatively stable. The concentrations of TP and PO_4^{3-}-P were higher in the disturbance than in the non-disturbance water body. The TP concentrations increased with time in non-disturbance sediments. The above results indicated that the disturbance increased TP and PO_4^{3-}-P in the water body sediments. Previous studies have reported that increases in the disturbance velocity can enhance the disturbance intensity in sediments, causing an increase in the suspended solid concentration, total phosphorus concentration in the overlying water, and release ability of phosphorus to overlying water from enhanced sediments (Tong et al. 2017). These observations could be explained by the release of absorbed phosphorous by the particles into the water body through sediment re-suspension at the sediment-water interface before the release reached equilibrium.

The release fluxes of PO_4^{3-}-P reached the highest level in the disturbance water body at 10 days, after which it gradually declined. The highest PO_4^{3-}-P release fluxes of 0,
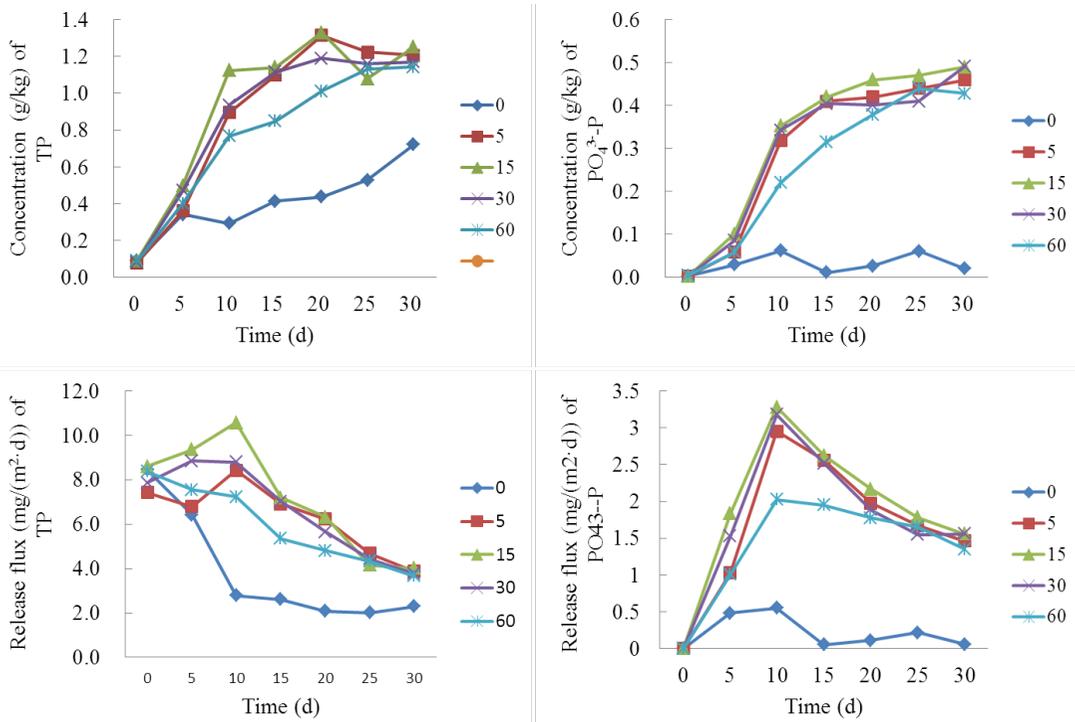
Fig. 3: Release concentrations and fluxes of TP and PO_4^{3-}-P in the disturbance and non-disturbance water bodies. The 0 represents concentrations in the non-disturbance water body; the 5-60 represents concentrations in the disturbance water body.

5, 15, 30, and 60 L.h^{-1} were 0.55, 2.96, 3.28, 3.18, and 2.03 mg.(m^2·d)$^{-1}$, respectively. The release fluxes of TP, PO_4^{3-}-P were higher in the disturbance than the non-disturbance water body, suggesting that the disturbance increased the release of TP and PO_4^{3-}-P in sediments.

Effect of Disturbance on the Release and Speciation of N and P in Sediments

In this study, the correlation between TN, NH_4^+-N, TP and PO_4^{3-}-P concentrations and DO, Eh, pH, and EC contents was analyzed. The results showed that the concentrations of TN, NH_4^+-N, TP, and PO_4^{3-}-P were negatively correlated with DO (Table 3), and the correlations of TN, NH_4^+-N, with DO were significant. These findings indicated that nitrogen and phosphorus release from sediment into the water body was

affected by DO. Previous studies have shown that nitrogen and phosphorus release in the water-sediment interface is influenced by many factors, such as temperature, pH, DO, the concentration of organic matter, and the oxygen state at the water-sediment interface, which is strongly correlated with the nitrogen and phosphorus transport and release rate (Beutel et al. 2008, Ding et al. 2016). Aerobic conditions can inhibit the release of nutrients from sediments to overlying water (Nausch et al. 2009, Wang et al. 2016). Improving the DO concentration at the water-sediment interface is an important tactic to control the release of sedimentary nutrients in a lake (Wang et al. 2020).

There were significant correlations between the different disturbance water bodies for TN and NH_4^+-N, while no significant correlation was found between disturbance and

Table 3: Correlation between TN, NH_4^+-N, TP, and PO_4^{3-}-P with pH, DO, Eh and EC.

Nutrients	pH	DO	Eh	EC
TN	-0.044	-0.621[**]	-0.512[**]	0.401[*]
NH_4^+-N	0.012	-0.453[**]	-0.394[*]	0.258
TP	0.483[**]	-0.327	-0.716[**]	0.734[**]
PO_4^{3-}-P	0.497[**]	-0.130	-0.562[**]	0.582[**]

* Significance at the 0.05 probability level.
** Significance at the 0.01 probability level.
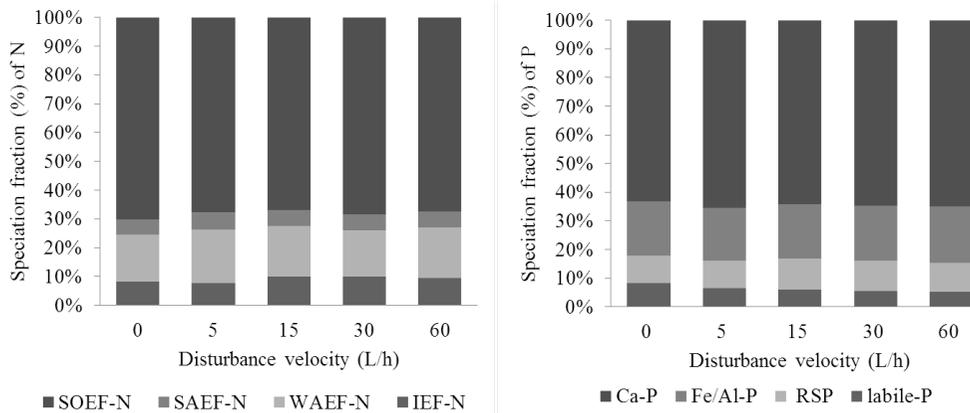
Fig. 4: Speciation distribution of N and P in sediments.

non-disturbance water bodies, which indicated that the nitrogen release process from sediments to the water body was the same in the disturbance body. The contribution of ammonia nitrogen released from the sediment to total nitrogen was the largest among all nitrogen components (Chen et al. 2015). Studies have reported that the nitrogen forms released from interstitial to overlying water are mainly NH_4^+-N, followed by NO_3^--N, and most of this nitrogen released from sediments is due to the degradation of organic matter (Markou et al. 2007).

The speciation fractions of N and P in sediments expressed as percentages to their total concentrations are shown in Fig. 4. The distribution patterns of the percentages for N or P nutrient speciation fractions were similar in disturbance and non-disturbance sediments. The percentage of SOEF-N was greater than 60% of their total concentrations in both disturbance and non-disturbance sediments, and the percentage of IEF-N was less than 10% of their total concentrations. Regarding phosphorus in disturbance and non-disturbance sediments, Ca-P accounted for more than 50% of the total concentration, and Labile-P was less than 10%. This result is consistent with the speciation fractions of N and P in sediment from Dianchi Lake (Li et al. 2012). The SOEF-N was primarily made up of organic nitrogen, and its content was primarily linked to organic matter, making it a minor contributor to lake eutrophication. In the transferable nitrogen fractions, this component was the hardest to release. It might, however, be converted to a bio-available pool through nitrogen mineralization, making it a possible nitrogen source. The IEF-N was easily released into the water as an ion-exchangeable form, which is critical for N cycling. Therefore, IEF-N release and migration cannot be ignored. The Ca-P was considered a relatively stable fraction of sedimentary P and contributed to a permanent burial of P in sediments, and it was generally regarded as autogenetic with little relevance to the eutrophic status (Kaiserli et al. 2002).

The percentages for a certain speciation fraction of nitrogen or phosphorus were not remarkably different between disturbance and non-disturbance sediments, suggesting an unobvious influence of disturbance on N or P speciation.

CONCLUSION

The dynamic release process of N and P in the different disturbance and non-disturbance water bodies and their effect on water quality were studied through simulation experiments. The release characteristics of N and P at different disturbance velocities were the same, and the release fluxes of TN, NH_4^+-N were higher in the non-disturbance than the disturbance water body. The release fluxes of TP and PO_4^{3-}-P were lower in the non-disturbance than the disturbance water body, which indicated that the disturbance increased the release of TP and PO_4^{3-}-P in sediments. The TN and NH_4^+-N in the sediment were released into the water body rapidly in the early 0-10 days for disturbance and non-disturbance water bodies, and the TP and PO_4^{3-}-P gradually increased in the disturbance water body and then stabilized after 20 days. The concentrations of TN, NH_4^+-N, TP, and PO_4^{3-}-P were negatively correlated with DO, and the correlations of TN, NH_4^+-N with DO were significant. The percentages of a certain speciation fraction of N or P were not different between disturbance and non-disturbance sediments. This study suggested that P release in disturbance sediment for rural ditches should not be overlooked, and its release and migration should be monitored with great concern for the environmental protection of rural regions.

ACKNOWLEDGEMENTS

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