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Effect of water-flow on nutrient mitigation from surface water in drainage ditches

Shuhui Huang [1], Huanqiang Liu [1], Zijun Yan[1] , Hailuo Sun[1], Minghua Zhang [1, 2], Randy A. Dahlgren[2] and Xuedong Wang [1]*

*[1] School of Environmental Science and Public Health, Wenzhou Medical College, Wenzhou, 325035, P.R. China. [2] Department of Land, Air and Water Resources, University of California, Davis, CA 95616, USA. *e-mail: zjuwxd@yahoo.com.cn*

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Abstract

Water quality is easily impacted by agricultural planting and drainage systems flowing into rivers. In this investigation, the effects of agricultural drainage ditches located in Sanyang wetland, Wenzhou, China, were studied for their ability to mitigate soluble inorganic nitrogen and phosphate under different sampling times and water-flow conditions. A significantly decreasing trend of NH_4-N concentration in drainage ditches was observed with increasing distance under three water-flow velocities (0.03, 0.06 and 0.1 m^3/h). The concentrations of NH_4-N varied at different times during each day under 0.3 m^3/h water-flow, with higher concentrations from 11:00 to 23:00 than at other times. There were significant correlations between on-site NH_4^+ and filtered NO_2-N (r = 0.54236, α<0.001), and between on-site NH_3 and filtered NO_2-N (r = 0.52867, α<0.001). The different dynamic trend between filtered NO_2-N and NO_3-N may have involved the conversion of nitrate to ammonium and denitrification. No significant difference of PO_4^{3-} concentration was observed over distances from 20 to 70 m on the 1st, 3rd, 5th or 7th day of retention under 0.03 m^3/h water-flow conditions. These results can provide a better understanding of nutrient mitigation under different conditions of hydraulic retention time.

Key words: Drainage ditches, water-flow, ammonium, nitrate, phosphate.

Introduction

Drainage ditches are commonly used to remove surface runoff from agricultural lands. Under the current farming practices, drainage ditches are typically designed only to satisfy the drainage requirement, and thus the drainage capacity of the field ditches should be significantly reduced. In America, the design of drainage systems has gone through several stages over a long period from 1950 to 1980, and after years of modification the original salinity problems have been eliminated [1, 2]. Researchers are now paying increasing attention to the ditch ecosystem and its environmental benefits [3]. Some agricultural ditches are constructed with the function of mitigating pesticides and nutrients. Lot of studies have demonstrated the positive role of vegetated agricultural drainage ditches in mitigating pesticides [1, 3, 4], while fewer have investigated their use in nutrient mitigation. Moore *et al*. [5] found that agricultural ditches were able to mitigate nutrients, while no statistically significant differences were observed in ammonia (NH_3), nitrate (NO_3^-) or dissolved inorganic phosphate (PO_4^{3-}) percent load reduction between vegetated and non-vegetated ditches. Jordan *et al*. [6] reported 25% ammonium (NH_4^{+-}) removal in a two-year study of the wetland receiving inflow from an agricultural watershed. The non-degraded wetland significantly improved water quality by reducing average loads of total suspended sediments, NO_3^-, and *Escherichia coli* by 77, 60 and 68%, respectively. Retention of total N, total P, and soluble reactive P was between 35 and 42% of the loads entering the reference wetland [7]. The effect of controlled drainage on reducing nitrogen load has earned it the title as one of the best management practices in many American states [8, 9]. However, limited number of reports concerning the effect of hydrological factors on nutrient mitigation in ditches could be found.

In this study, the effects of different water-flow velocities in drainage ditches on reducing loads of NH_4^+, NO_3^-, nitrite (NO_2^-) and dissolved inorganic phosphate (PO_4^{3-}) are investigated. The aim of this study was to assess the temporal mitigation of nutrients in ditches and the quantitative removal of nutrients under different hydraulic conditions.

Materials and Methods

Location of the investigated ditch: The agricultural drainage ditches chosen for this nutrient mitigation research were located in Sanyang Wetland, Wenzhou, China (Fig. 1a). These ditches were used to drain vegetable fields, and the water in ditches was pumped from the neighboring Xiongxi river, and discharged back into the river. Each ditch was about 70 m in length with a mean width of 0.5 m and mean depth of 0.8 m (Fig. 1b).

Simulated water-flow event: River water was pumped into a water tank with an approximate volume of 31.5 m^3 (7 m in length, 3 m in width and 1.5 m in height). Then the continuous water-flow was controlled and discharged into the investigated ditches. Four water-flow velocities were maintained at 0.03, 0.06, 0.1 and 0.3 m^3/h, which correspond to 10, 5, 3 and 1-d hydraulic retention times of outflow events, respectively.

Sample collection and analysis: The YSI instrument (model 6920, YSI company, USA) was used for on-site monitoring of the following water indices: temperature (T), electric conductivity (EC), salinity, pH, dissolved oxygen (DO), NH_4^+ and NH_3. The sampling sites were set at distances of 0, 5, 10, 20, 30, 40, 50, 60 and 70 m from the water tank. The surface water samples from different

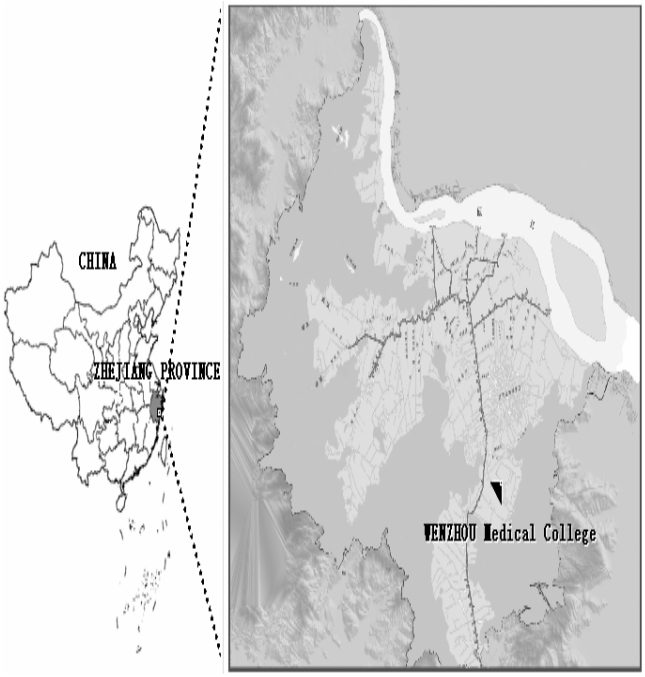

Figure 1a. Sanyang Wetland, Wenzhou, China.

Figure 1b. The experimental ditch.

sites in the ditches and the river were collected in 500 mL polyethylene bottles. The collected samples were stored immediately in ice boxes and brought to the laboratory for analysis. Samples were passed through a 0.45-μm millipore polycarbonate membrane filter. Concentrations of NH_4-N, NO_3-N, NO_2-N and PO_4^{3-} in the filtrate were analyzed with a Bran+Luebbe AutoAnalyzer II (British Seal Analytical Instruments Co., Ltd).

The statistical analyses were performed using the SAS software [10] in order to investigate the differences and correlations of water quality parameters in different sites of the ditches or river.

Results and Discussion

Water quality of the investigated river, the Xiongxi river, is a branch of Wenruitang River, Wenzhou, China, and its average pH, salinity, EC and DO were 7.11, 464.53 mg L^{-1}, 0.22 mS cm^{-1} and 3.22 mg L^{-1}, respectively,. The on-site concentrations of NH_4^+ were 5.94 and 0.083 mg L^{-1}, indicating that the content of NH_3 was minor compared to NH_4-N. The concentrations of NH_4-N, NO_3-N, NO_2-N and PO_4^{3-} were 3.77, 4.16, 0.08 and 0.23 mg L^{-1}, respectively, in river. Thus, the content of NH_4-N was higher than the regulated water quality. However, the soluble PO_4^{3-} was less than the index value listed in water quality, suggesting that the main pollutant in Wenruitang River was nitrogen.

The water tank was filled with pumped river water for 6 h before initiating water-flow into the ditches, and the effect of retention in the water tank on NH_4-N and NO_3-N because of the presence of microorganisms was negligible.

Ammonium variation in drainage ditches: The mitigation of NH_4-N in drainage ditches under different water-flow rates is shown in Fig. 2 and concentrations of NH_4-N under different timing conditions are depicted in Fig. 3. A significant decreasing trend of NH_4-N concentration in drainage ditches could be observed for the three water-flow rates (0.03, 0.06 and 0.1 m^3/h). For the 0.03 m^3/h effluent event, NH_4-N concentration was higher on the 1st, 3rd and 5th day retention intervals, while it was significantly reduced on the 7th and 10th day retention intervals. However, it is worth noting that a dramatic increase occurred at the end of the ditch (70 m distance). For the 0.06 m^3/h effluent event, the lowest concentrations of NH_4-N in drainage ditches were found on the 4th day retention interval, and no significant difference of concentration was observed at different sampling distances. However, it was increased on the 5th day retention interval. In addition, the concentrations of NH_4-N show a regular change at different times of each day for 0.3 m^3/h effluent event. From 11:00 to 23:00, the concentrations were higher than those at other times, while an acute reduction at 3:00 and 7:00 was observed (Fig. 3d). In addition, it is interesting that the concentration showed an obvious increase at the distance of 70 m, when compared with 60 m, at any time during one day.

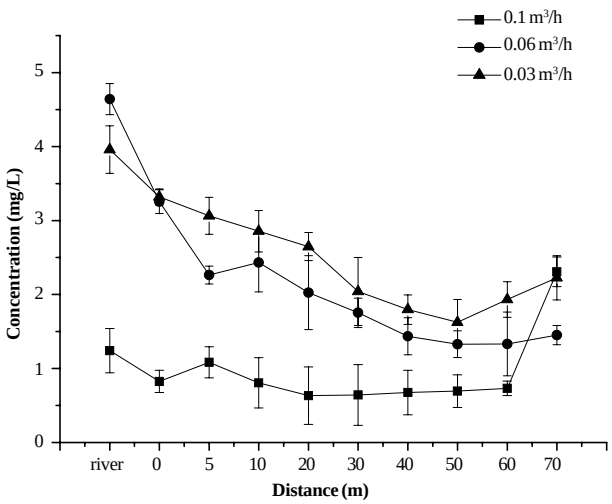

Figure 2. NH_4-N variation of different flow rate in drainage ditches.

A significant correlation existed between on-site NH_4^+ and NH_3 in surface water ($r = 0.62683$, $\alpha<0.05$). However, this was not the case between either on-site NH_4^+ and soluble NH_4-N. One possible reason for these observations is the adsorption of NH_4^+ to the suspended particles. Additionally, the content of NH_4^+ was easily affected by environmental factors such as temperature and wind.

Biogeochemical processes that occur within drainage ditches

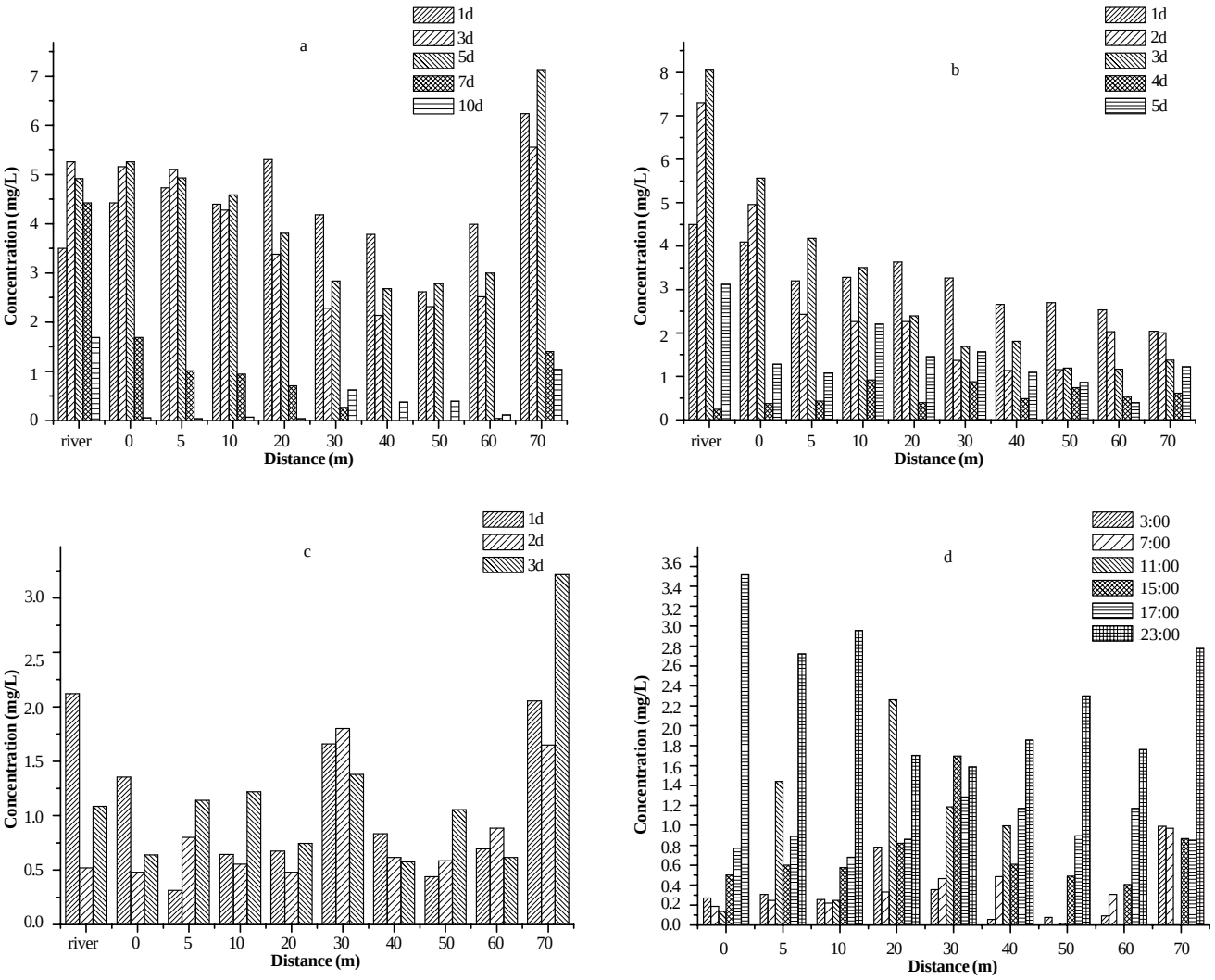

Figure 3. Concentrations of NH_4-N under different water-flow rates in ditches and the river (a: 0.03 m^3/h water-flow; b: 0.06 m^3/h; c: 0.1 m^3/h; d: 0.3 m^3/h).

can effectively remove a variety of pollutants from the water column. These processes include sedimentation and burial (adsorbed P, pesticides, suspended sediments, particulate organic carbon, pathogens), microbial transformations to gaseous forms (denitrification, methanogenesis), plant and microbial uptake of nutrients, microbial degradation (oxidation-reduction) of pesticides and other organic compounds, and predation within the food web (pathogen consumption). Quantification and comparison of influent and effluent event loads assessed the combined impacts of all of these processes of drainage ditches [7].

Nitrate variation in drainage ditches: Figs 4 and 6 demonstrate the mitigation of NO_3-N and NO_2-N loads, respectively, in drainage ditches under different water-flow rates, and the concentrations of NO_3-N for the different effluent events are shown in Fig. 5. Among all the detected NO_3-N concentrations, higher values were observed on the 1st and 10th day retention intervals, while the lower values on the 3rd, 5th and 7th day retention intervals for the 0.03 m^3/h effluent event. Moreover, an increase was found at the end of the investigated ditch (70 m). Under 0.06m^3/h water-flow, lower concentrations of NO_3-N in drainage ditches were observed on the 2nd, 3rd and 5th day retention intervals, while higher concentrations were observed on the 1st and 4th day retention intervals. Concentrations of NO_3-N in drainage ditches were low on the 3rd day from 10 to 40 m, but remained stable on the 1st day retention interval for the 0.06m^3/h effluent event. Additionally, as the distance increased, concentrations of NO_3-N decreased for the 0.3 m^3/h effluent event.

The different trends observed between filtered NO_2-N and NO_3-N could possibly result from the important roles of NH_4^+ and NO_3^- in the process of denitrification.

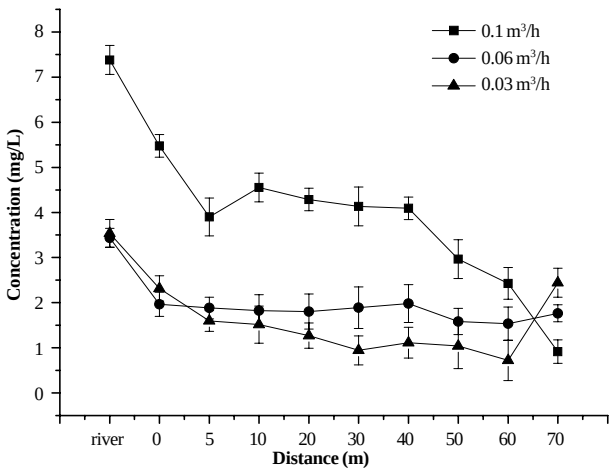

Figure 4. NO_3-N variation in drainage ditches.

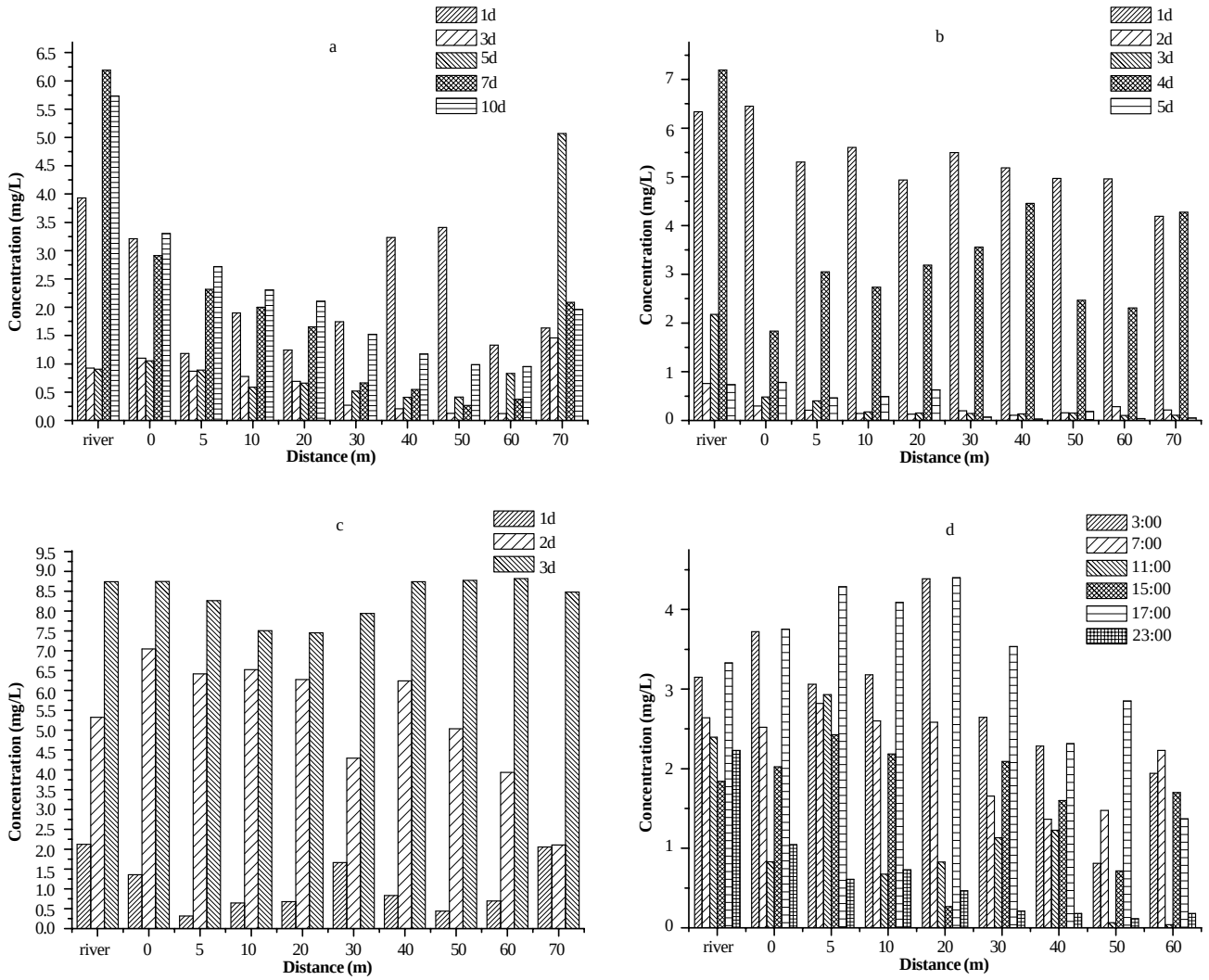

Figure 5. Concentration of NO_3-N under different water-flow rates in ditches and the river (a: 0.03 m^3/h water-flow, b: 0.06 m^3/h, c: 0.1 m^3/h, and d: 0.3 m^3/h).

Phosphate variation in drainage ditches: The mitigation of PO_4^{3-} in drainage ditches under different water-flows is shown in Fig. 7. As can be seen from Fig, 8, concentrations of PO_4^{3-} in drainage ditches ranged from 0.05 to 0.5 mg L^{-1}, showing a very low level for all the different effluent events. No significant differences in concentrations were noted from 20 to 70 m on the 1st, 3rd, 5th and 7th day retention intervals for the 0.03 m^3/h effluent event. However, the higher concentrations were observed on the 10th day retention interval. In addition, no available results were obtained for 0.06 and 0.1 m^3/h water-flow events. McDowell and Sharpley found that soluble phosphate has an obvious diurnal variation under 0.6 m^3/h water-flow and that a high percentage of phosphorus, i.e. up to 35% of the P adsorbed during flow, may be attributed to the sediment microbial community [11, 12]. The similar result occurred in our investigation, up to 50% of P was adsorbed at the distance of 70 m for the 0.06 m^3/h effluent event.

Relationship of nutrient concentrations with some water quality parameters: The correlation coefficients among water quality parameters and nutrient concentrations are summarized in Table 1. Obviously, pH and DO had no significant effects on each nutrient concentration. However, EC had very significant effects on NH_4-N and NO_2-N, and salinity had significant effects on these two nutrients. Research in arid and semi-arid areas has shown that while maintaining salt balance, controlled drainage can significantly reduce drainage and save irrigation water use [13]. Since microbes are known to participate in nitrate denitrification, the significant correlation among salinity and soluble NH_4-N and NO_2-N in this study could result if differences in salinity were great enough to affect microbial activity. However, more study is required to directly demonstrate this hypothesis.

Effects of distance on nutrient mitigation: As can be seen from Fig. 1, the concentration of NH_4-N showed a gradually reducing trend as the distance increased from 0 to 50 m followed by an increasing trend from 50 to 70 m for each effluent event. Nitrate concentration decreased from 0 to 50 m for the 0.03, 0.06 and 0.1 m^3/h effluent events. However, for the 0.1 m^3/h effluent event, it increased from 50 to 70 m. NO_2-N is known to be a pivotal molecule in nitrification and denitrification processes. In this investigation, NO_2-N concentrations decreased as NO_3-N increased from 0 to 40 m for 0.03, 0.06 and 0.1 m^3/h effluent events. At the distance of 40 to 70 m, concentrations of NO_2-N were very low, sometimes below detectable levels.

As the distance increased, the concentrations of PO_4^{3-} dropped sharply from 0 to 40 m for 0.03 m^3/h effluent event, and remained stable from 40 to 70 m. Under 0.06 m^3/h water-flow, it showed an increasing trend from 0 to 10 m, then a decreasing trend from 10 to

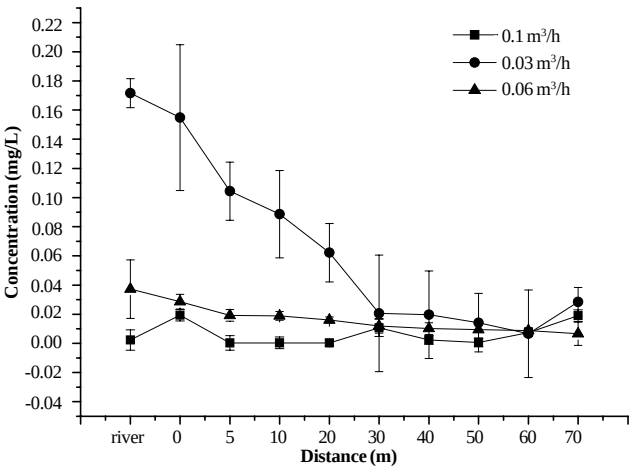

Figure 6. NO_2-N variation in drainage ditches.

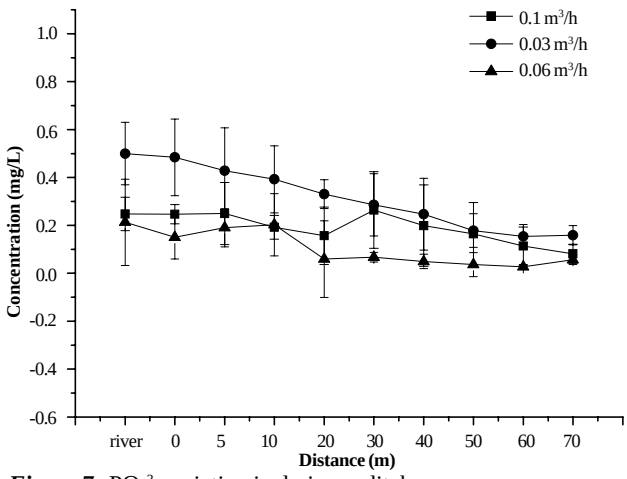

Figure 7. PO_4^{3-} variation in drainage ditches.

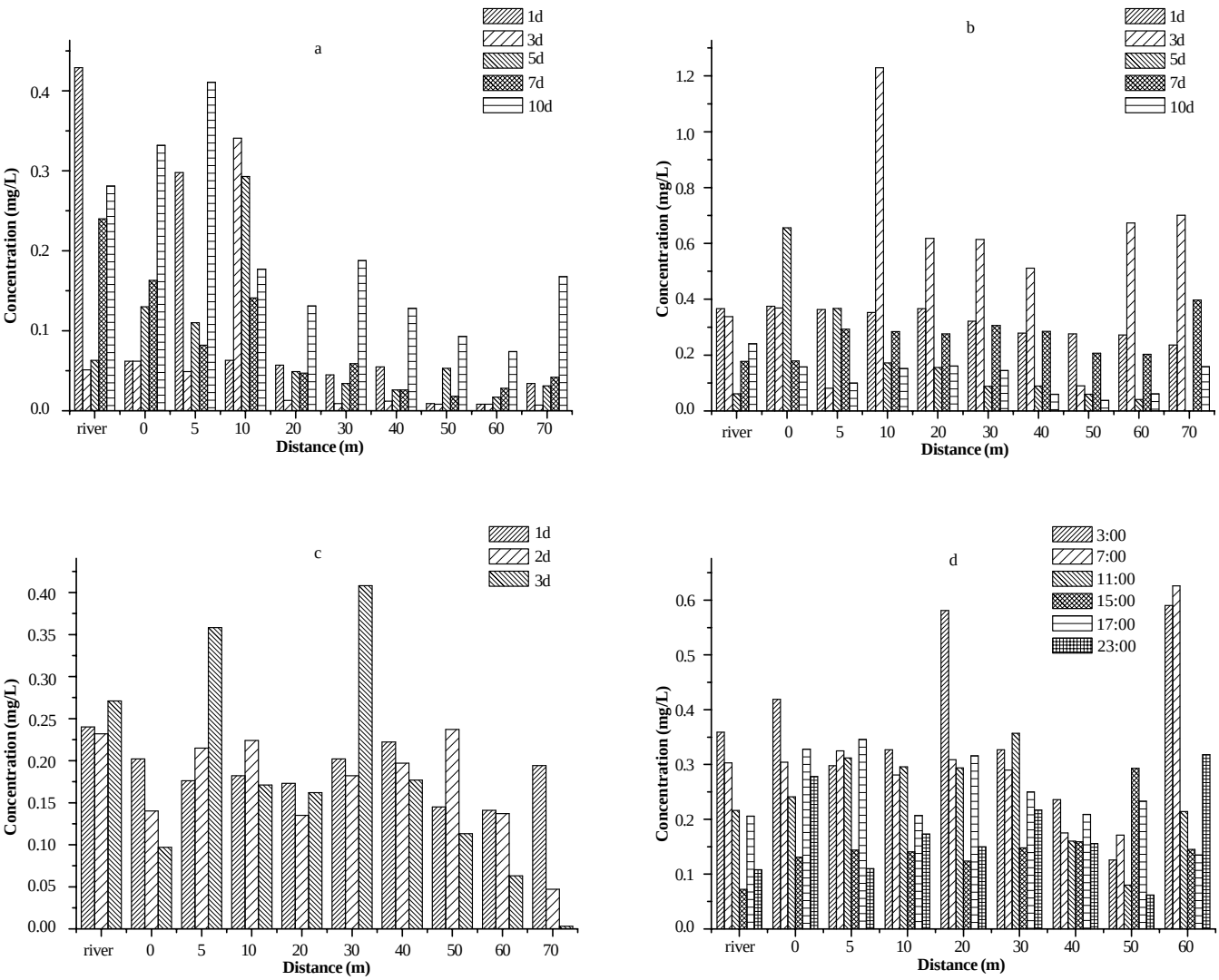

Figure 8. Concentration of PO_4^{3-} under different water-flow rates in ditches and the river (a: 0.03 m³/h water-flow, b: 0.06 m³/h, c: 0.1 m³/h, d: 0.3 m³/h).

Table 1. The relationships between some parameters with nutrients.

	NH_4^+	NO_3^-	NO_2^-	PO_4^{3-}
pH	-0.14183	-0.05923	0.03050	0.33189
EC	-0.48793^{++}	-0.14446	-0.51036^{++}	-0.22139
Salinity	-0.40829^{+}	-0.06915	-0.37293^{+}	-0.15406
DO	0.19488	-0.15522	-0.02016	-0.24720

++ means very significant, + means significant.

50 m. Under 0.1m^3/h water-flow, it remained stable from 0 to 40 m, and decreased gradually from 40 to 70 m. However, the statistical analyses showed no significant differences between concentrations of PO_4^{3-} and the distances in all water-flow events. Agricultural activities play a major role as point and non-point (diffuse) sources of pollutants such as phosphorus (P) to receiving waters in many countries around the world. With increased worldwide legislation, controlling non-point source inputs to receiving waters has become a major environmental issue. Phosphorus, derived from non-point sources such as drainage networks, has become a major contributor to receiving waters in recent years [14]. The low background of phosphate in drainage ditches in this study, suggest that they are not major sources of phosphate runoff to rivers.

Conclusions

The mitigation of NH_4-N and NO_3-N from ditches varied under the different conditions of hydraulic retention time. As the distance increased, concentrations of NH_4-N and NO_3-N decreased from 0 to 50 m for 0.03, 0.06 and 0.1 m^3/h water-flow events in the investigated ditch. As the distance increased, the drainage ditch was able to adsorb the high concentrations of PO_4^{3-}. These results were obtained under natural conditions, i.e. the water came from the original Wenruitang River. Therefore, further work is required on the effect of standard additions of nutrients on the mitigation of each nutrient constituent under experimental conditions. There was a very significant correlation between on-site NH_4^+ and NH_3 in surface water, but not between on-site NH_4^+ and filtered NH_4-N, or between on-site NH_3 and filtered NH_4-N. The possible reason for this difference is the adsorption of NH_4^+ to the suspended particles. Because the transport of soluble PO_4^{3-} to fresh water ecosystems is strongly affected by the planting and ditch sediment, future efforts will explore the adsorption of PO_4^{3-} by the different vegetation and ditch sediments.

Acknowledgements

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