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Window phase analysis of nutrient losses from a typical rice-planting area in the Yangtze river delta region of China

Shuang He^{1,2†}, Fayong Li^{1,3†}, Xinqiang Liang^{1*} , Hua Li⁴, Sheng Wang¹, Yingbing Jin¹, Boyi Liu¹ and Guangming Tian¹

Abstract

Background: Rice paddy wetlands may serve as a nutrient source or sink in agricultural ecosystems. However, the pattern of nutrient loss on a watershed scale is not clear. A year-round on-site observation study based on 6-h intervals was conducted. Rainfall, temperature, runoff nutrient concentrations, and adjacent stream water samples were automatically monitored to uncover the temporal changes in the runoff losses of the predominant nutrient proxies (total N and total P) from a typical rice-planting area (120 ha) in the Yangtze river delta region of China.

Results: A high total N concentration in the rice-planting area was observed during the rice-planting season; however, significant fluctuation in the total P was evident throughout the year. The Δ total N (drainage minus stream) parameter showed negative values with a mean of -0.25 mg L^{-1} , while Δ total P showed positive values with a mean of 0.06 mg L^{-1} . The annual average N and P runoff from paddy field were 11.6 kg ha^{-1} and 1.5 kg ha^{-1} , respectively. The window phases for the total N loss were mainly concentrated in the rice-growing season. However, the window phase for the total P loss was more dispersive throughout the year. No apparent relationships were found between rainfall and N and P concentrations by self-organizing map analysis.

Conclusions: The high-resolution monitoring, in this study, suggested that nutrient loss loading rather than nutrient concentration was strongly related to surface runoff. Therefore, fertilization before high-intensity rainfall should be avoided to mitigate the nutrient runoff losses and maintain the rice wetland eco-function.

Keywords: Drainage water, Rice field, Self-organizing maps, Stream, Total phosphorus, Total nitrogen

Background

High levels of nutrient losses from agro-ecosystems, such as paddy fields, in which nutrients flow into downstream lakes, reservoirs, and other open water bodies can cause eutrophication, including excessive algal blooms, in the adjacent receiving streams [1–4]. Rice paddy fields account for 50% and 14% of global irrigation water and

fertilizer consumption, respectively, owing to frequent irrigation and excessive fertilization [5]. The paddy field is also one of the most important sources of nutrient losses to streams in the Yangtze river delta region of China, owing to the addition of chemical and organic nitrogen (N) and phosphorus (P) fertilizers (residue and manure), intensive puddling, and alternating flooding and draining management [6]. Today, the rice-planting area covers more than 18 million ha in this region [6, 7], whereby the application rates of N and P fertilizers have reached or exceeded 300 kg ha^{-1} and 200 kg ha^{-1} , respectively [8]. Moreover, the rainfall in some regions such as Zhejiang province can be higher than $1500 \text{ mm year}^{-1}$, mostly occurring during the rice-planting season. Therefore,

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excessive surface runoff from the paddy field in the Yangtze river delta region of China may occur.

Lowland rice paddy fields are vital for both world food production and regional nutrient management. Many researches have proved that rice fields would not always export N and P to ambient water bodies, and rice paddy fields were considered as wetlands to retain nutrients [9, 10]. Thereby, due to the soil nutrient retention and rice uptake [11], the runoff nutrient concentrations may be lower than the receiving stream. However, when heavy rainfall occurs following fertilization, the runoff nutrient concentrations become higher than those in the receiving stream [12], which can be defined as a discharge window phase (or a critical discharge period) of N and P from paddy fields. At present, the window phases of N and P losses from rice paddy fields are still unclear, which brings challenges to nutrient management in this ecosystem.

Nitrogen and phosphorus losses from paddy fields usually occur predominantly through surface runoff rather than infiltration because of a plow pan that prevents downward water infiltration [13]. Some studies have shown that N and P runoff losses are affected by soil and climatic parameters, as well as agricultural practices, including soil texture, cover crops, the application rate of N and P fertilizers, timing and method, soil tillage, irrigation regimes, and rainfall intensity and amount [14–16]. A small-scale in situ experiment show that total P (TP) runoff losses ranged from 0.18 to 1.51 kg ha⁻¹, and particulate P (PP) runoff losses accounted for 58–77% of the seasonal TP lost [14]. They further reveal that nutrient loss loading varied with seasons [14]. However, current research on nutrient runoff in large-scale rice-planting areas has been rarely performed. Moreover, the discharge window phase and dissipation law of N and P loss loading in planting areas are rarely reported.

Rainfall is one of the most critical factors affecting N and P loss, as it is associated with the drainage of rice fields. Field runoff caused by heavy rainfall in the rainy season causes a certain amount of N and P nutrient loss. Guo et al. [17] found that the annual P loss was 0.75 kg hm⁻² using field surveys of rice fields in the Taihu Lake area. However, when several rainfall events took place during cultivation and fertilization, the annual P loss increased to 5.49–17.68 kg hm⁻² under current irrigation and drainage conditions [18]. Nevertheless, it is still unclear how rainfall affects the soil N and P loss loadings. Inevitably, seasonal fluctuations in the soil N and P loss loadings will result in changes in the water quality of the external receiving water bodies, owing to the seasonal variations of rainfall.

Hence, it is crucial to uncover the effects of rainfall and subsequent runoff amount on the nutrient loss loading

from the rice fields in the Yangtze river delta region. However, the nutrient runoff from rice fields, unlike that from upland fields, can be reduced by field bunds [19]; thus, the relationship between rainfall and nutrient runoff loss is more complicated in the rice fields. Many researchers [20, 21] have employed monitoring data to investigate the role of rain events in the N and P loss to adjacent streams. Other studies [22, 23] have observed a decrease in the total N and P concentrations with time or with the number of rainfall events. However, there is no definite conclusion concerning the relationship between the rainfall amount and the total N and P concentration in the runoff and adjacent stream water because of the complex processes of N and P transport [24]. To date, the relationship between the rainfall and nutrient runoff losses from agricultural fields is often explored by using monthly or bimonthly rainfall monitoring data [25–28]. We consider that this approach cannot accurately predict agricultural nutrients, such as N and P runoff over the rainfall amount. One alternative is to use high-resolution daily rainfall vs. water-quality monitoring data, which can facilitate the retrieval of timely dynamic variations of nutrient runoff losses under changing rainfall conditions [29, 30].

The objective of this study was to investigate the response of the total N and P concentrations to rainfall in the runoff versus the adjacent stream to the rice field system using 6-h interval monitoring data and the Self-Organizing Map (SOM) prediction approach. We hypothesized that: (1) there are window phases and dissipation periods for the runoff of N and P in the retention ditch of the paddy field. Additionally, the concentrations of N and P in the runoff are higher and lower than those in the external stream during the window phase and dissipation period, respectively. (2) The loss loadings of N and P in the runoff, rather than the concentrations of N and P of the paddy field ditches, are closely related to the amount of surface runoff caused by rainfall.

Materials and methods

The site description of rice plantation

The rice plantation area investigated in this study is located at Jinshan town, Hangzhou city, in the Yangtze river delta region of China. It covers a total of 120 ha rice fields with a single crop of late-season rice. This area has a subtropical monsoon climate, and the soil type of the rice field is hydromorphic paddy soil (ferric-accumulic stagnic anthrosols). The soil properties of the plow layer (0–20 cm) were as follows: pH 5.8 (1:5, soil/water), soil organic C 21.8 g kg⁻¹, total N 3.46 g kg⁻¹, mineral N 24.0 mg kg⁻¹, and total P 0.318 g kg⁻¹. A trench for receiving the excessive surface runoff water from the rice

plantation area was 5 m wide, 2.5 m deep, and 1850 m long.

Experimental design

Rice seedlings of a local late-season rice cultivar named Xiushui 134 (i.e., *Oryza sativa* L.) were mechanically transplanted on June 4, 2018. The entire rice plantation area was uniformly fertilized. Specifically, urea was applied in three splits for the late-season rice, i.e., 40% was basally applied (June 4, 2018), while another 40% was top-dressed at the tillering stage (July 5, 2018), and the remaining 20% was top-dressed at the panicle initiation stage (August 5, 2018). Full doses of superphosphate and potassium chloride were applied basally at the rates of 120 kg P₂O₅ ha⁻¹ and 120 kg K₂O ha⁻¹, respectively. The entire duration of the rice growth was 139 days, and the final harvests were completed on October 21, 2018. We followed the typical irrigation method for flooded rice in the region that consisted of irrigating the paddy field until the depth of 70 mm; then, when the field water level dropped to 10 mm, irrigation was repeated. Thus, the floodwater depths in the field fluctuated from 10 to 70 mm until rice maturity and drained 30 days before harvest [2].

A water monitoring station was set up at the end of the long trench to simultaneously take water samples from both the trench runoff and adjacent stream. The samples were taken every 6 h from Feb 10, 2018, to Jan 30, 2019, except when the trench water was frozen (Fig. 1). The nutrient proxies (i.e., total N, and total P) in these water samples were automatically analyzed by an on-line water-quality analyzer (NH₃-N-2000; TPN-2000, China,

Hangzhou Juguang Tech. Co.) at the monitoring station. Briefly, the total N and P concentrations in the unfiltered water samples from runoff and adjacent stream were determined calorimetrically according to the standard method [31] after they were digested with the K₂S₂O₈ solution. Meanwhile, a mini-meteorological station (HOBO-U30, America, Onset Computer Co.) was placed at the experimental site to collect the hourly rainfall data.

Calculation of nutrient runoff loss loading

The nutrient runoff loss loading was calculated from the nutrient concentration (mg L⁻¹) multiplied by the runoff amount (Rd) (mm) and rice plantation area. The following equation (Eq. 1) was used to calculate the runoff amount:

$$Rd = Rf \times 0.994 - 28.9598, \quad (1)$$

where Rf is the rainfall (mm) [32].

Data analysis

The linear correlations between the accumulated runoff and the total N and P loss loadings from the rice field system were analyzed using SPSS statistics (V.22) software. The results of the SOM prediction were evaluated using the correlation coefficients (*R*) and mean absolute scaled errors (MASE).

We used the SOM approach to visualize the relationships between the accumulated rainfall amount and the total P and N concentrations in the retention ditch and adjacent stream water. The SOM analysis was performed using the SOM toolbox (<http://www.cis.hut.fi/projects/somtoolbox/>) in Matlab (v. 7.11). The description of the

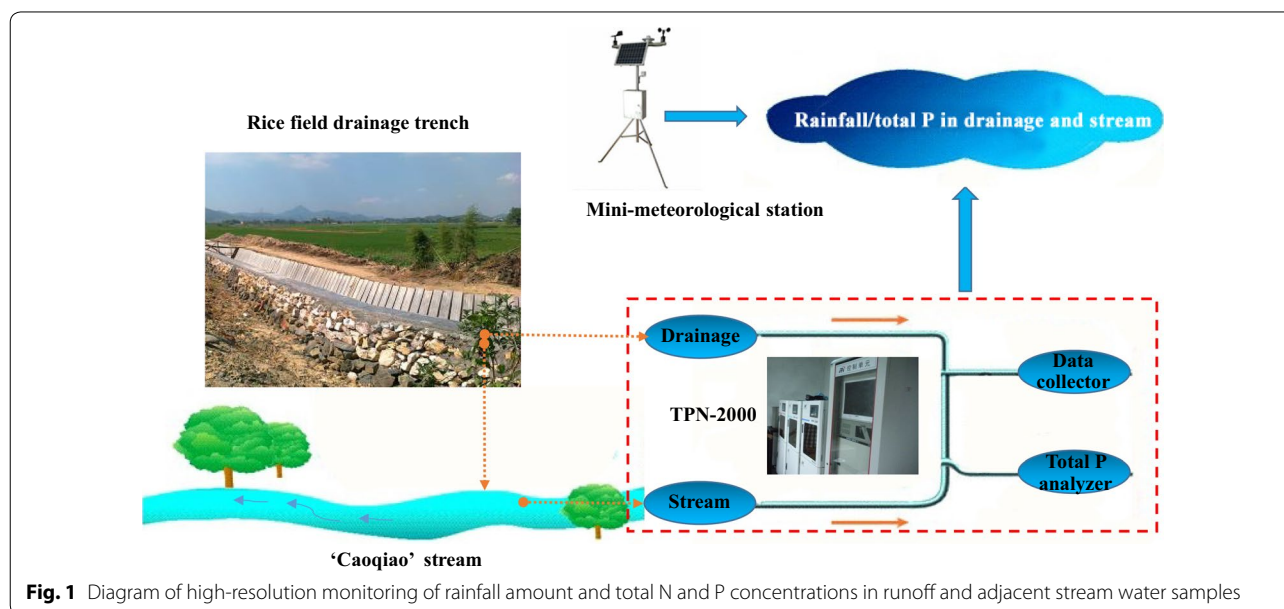


Fig. 1 Diagram of high-resolution monitoring of rainfall amount and total N and P concentrations in runoff and adjacent stream water samples

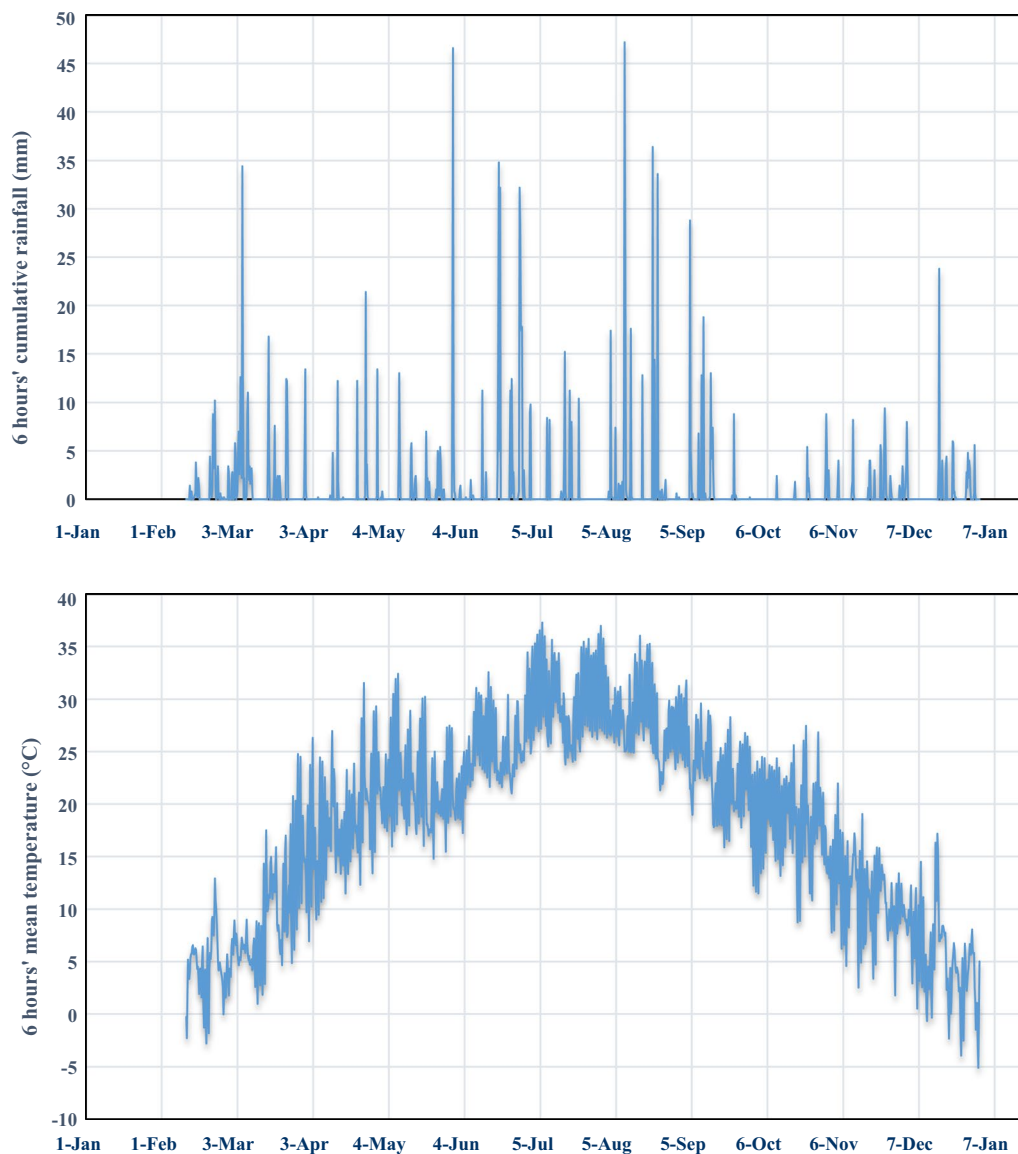


Fig. 2 Six-hour cumulative rainfall and mean temperature during the observation period

SOM approach can be found in previous studies [33–37]. In this study, we developed a dataset that included a 977×11 matrix, representing 977 samples with 11 measured parameters, i.e., H6, H12, H18, H24, H30, H36, H42, H48, total P and N concentrations in the runoff, and adjacent stream water. The abbreviations, H6–H48 indicate the accumulated rainfall amounts at 6–48 h water sampling intervals. The dataset was loaded into the Matlab workspace, and the abstract visualization process was performed after the installation of the SOM package. To perform this prediction, 684 data samples were randomly selected to be the training data, while the remaining 293 data samples were used as the testing data. Initially, the

data entries of the total P and N in the drainage water were eliminated from the testing dataset. After running the SOM analysis, the predicted total P concentrations were compared with the observed values.

Results

Temperature and rainfall records during the observation period

The 6-h cumulative rainfall over the entire year reached a value of 1468 mm (Fig. 2). The wettest months were July and August, with a 6-h cumulative rainfall of 328 mm. The mean values of the rainfall amount increased from H6 to H48; however, the maximum values did not

increase further after H30, indicating that the most considerable rainfall amount was within 30 h before the sampling event (data not shown). The water temperature reached a maximum of 37.29 °C between July and August, while the lowest temperature was − 5.01 °C (Fig. 2).

Nutrient concentrations and window phases

The mean value of the total N in the runoff was lower than that of the adjacent stream. The total N in the retention ditch water ranged from 0.31 to 7.89 mg L^{−1}, with a mean of 2.11 mg L^{−1}. Meanwhile, the corresponding values in the adjacent stream were 0.48–5.57 mg L^{−1} and 2.36 mg L^{−1} (Table 1). More than 38% of the total N concentration was higher than 2.0 mg L^{−1} (i.e., Class V of Chinese surface water quality guideline for streams) (Fig. 3). Contrary to the total N, the mean value of the total P in the runoff of the retention ditch water was higher than that of the adjacent stream. The total P in the retention ditch water ranged from 0.01 to 1.18 mg L^{−1}, with a mean of 0.24 mg L^{−1} (Table 1). Meanwhile, the corresponding values in the adjacent stream were 0–1.13 mg L^{−1} and 0.18, respectively, i.e., 6% higher than 0.4 mg L^{−1} (i.e., Class V of Chinese surface water quality guideline for streams).

However, the results (Fig. 4) based on the water sampling and measurements in a 6-h interval, show that the temporal changes of the total N and P concentrations in the rice-field drainage and adjacent stream water were not identical for most of the sampling events. Specifically, most of the Δ total N (i.e., total N in drainage minus total N in the stream) showed negative values with a mean of − 0.25 mg L^{−1}. Meanwhile, the values between June 22 and July 22 were positive with a mean of 1.75 mg L^{−1}, a maximum of 4.26 mg L^{−1} on July 12, and a minimum of 0.01 mg L^{−1} on July 18. These results show significant window phases in these periods. Although Δ total P (i.e., total P in drainage minus total P in the stream) showed positive values with the mean of 0.06 mg L^{−1}, negatives

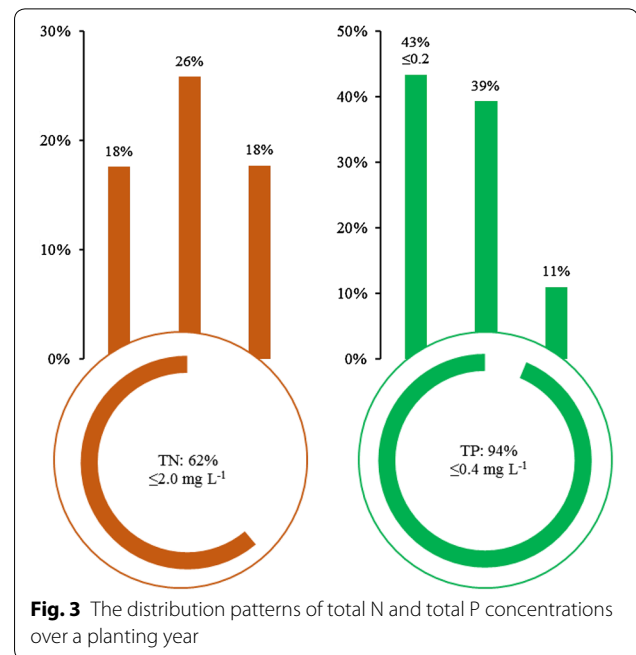


Fig. 3 The distribution patterns of total N and total P concentrations over a planting year

values were evident for the minimum (i.e., − 0.86 mg L^{−1}) and 25% percentile (i.e., − 0.01 mg L^{−1}), respectively. Even at the 75% percentile value, the total P in the rice-field drainage was marginally higher than that in the adjacent stream by 0.08 mg L^{−1}.

Further, the results (Fig. 4) show that most of the Δ total P values (i.e., 47.2% and 32.5% of the total observations) were within 0–0.1 mg L^{−1} and − 0.1–0 mg L^{−1}, respectively. The rest of the Δ total P values were above 0.1 mg L^{−1} (i.e., 17.9%) or below − 0.1 mg L^{−1} (i.e., 2.5%). The window phases of N and P showed different patterns. The window phases of N mainly appeared from June to July during the rice-growing season, while the window phases of P were more scattered and occurred throughout the rice-planting year (Fig. 4).

Table 1 Total N and P of rice-field drainage in retention ditch and adjacent stream water samples and the accumulated rainfall amount during the 6–48 h before the water samples were taken ($n = 977$)

	Total N (mg L ^{−1})			Total P (mg L ^{−1})		
	Ditch	Stream	$\Delta D - S^a$	Ditch	Stream	$\Delta D - S^a$
Mean	2.11	2.36	− 0.25	0.24	0.18	0.06
Median	1.70	2.21	− 0.51	0.22	0.17	0.03
Minimum	0.31	0.48	− 0.17	0.01	0.00	− 0.86
Maximum	7.89	5.57	2.32	1.18	1.13	1.04
25% percentile	1.14	1.56	− 0.42	0.15	0.12	− 0.01
75% percentile	2.77	3.07	− 0.30	0.28	0.22	0.08

^a Total N and P in retention ditch water minus that in the adjacent stream

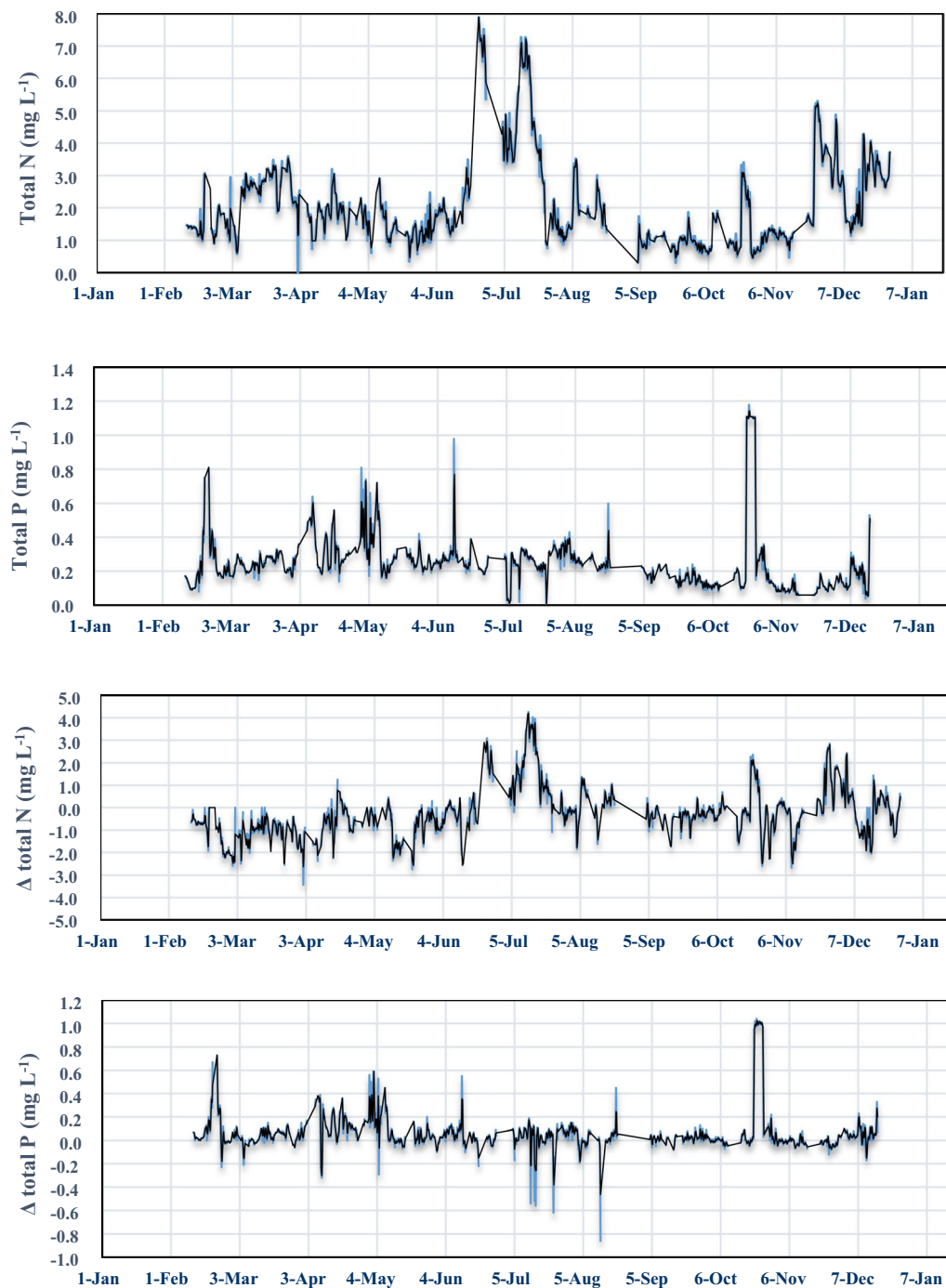


Fig. 4 Temporal changes in nutrient concentrations (total N and P) in runoff in the rice-planting area and difference in nutrient concentrations between runoff and adjacent stream water

However, the highest peak of the total N was observed from June 22 to July 16, and the highest peak of the total P was observed on August 12 (at 7 p.m.) for rice-field drainage and on October 22 (at 7 a.m.) for adjacent stream water, respectively.

Nutrient runoff loss loadings from the rice plantation area

The results of the total N and P loss loadings from the rice plantation area are given in Fig. 5. The annual average N and P runoff from paddy field were 11.6 kg ha⁻¹ and 1.5 kg ha⁻¹, respectively. At each runoff event, most

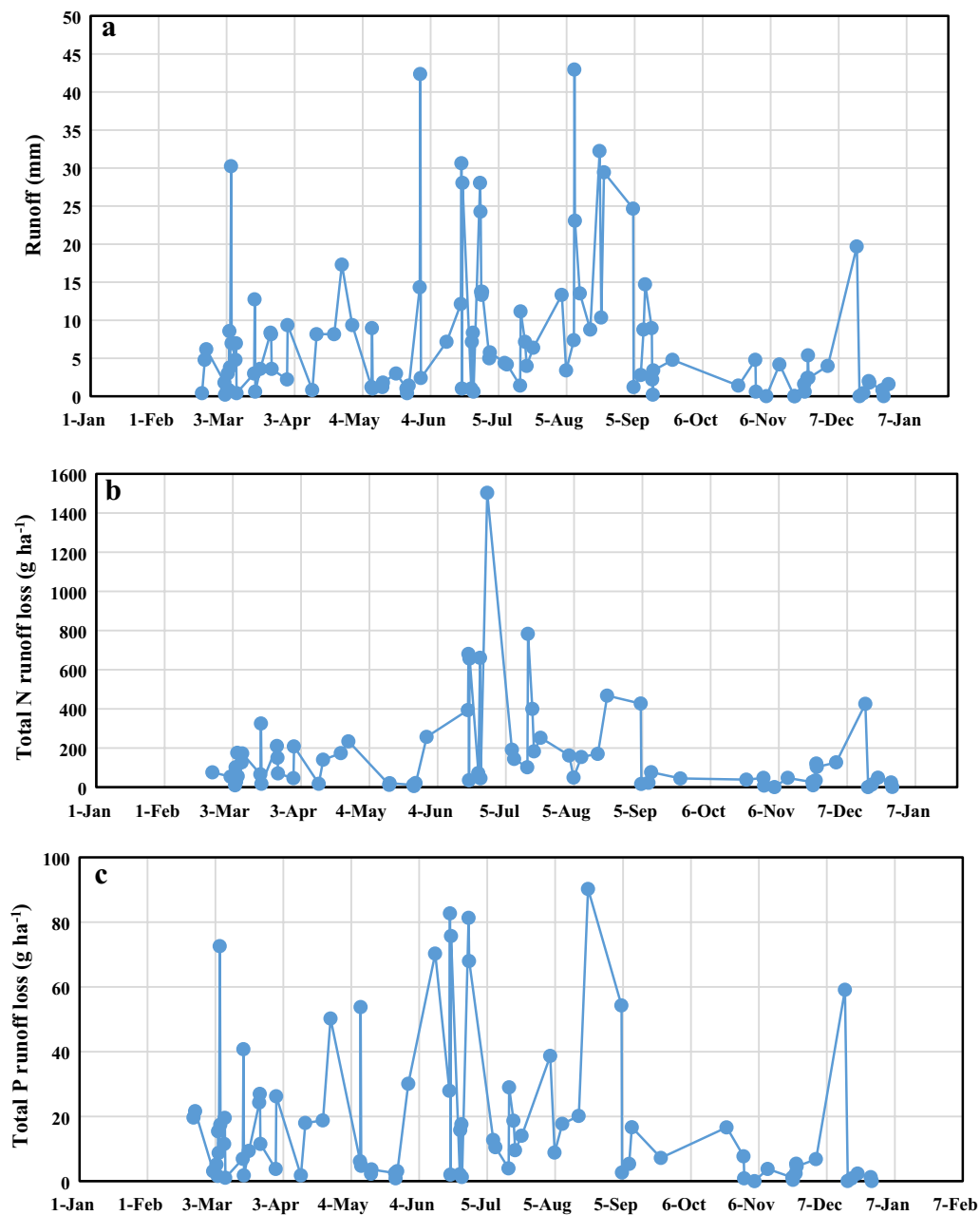


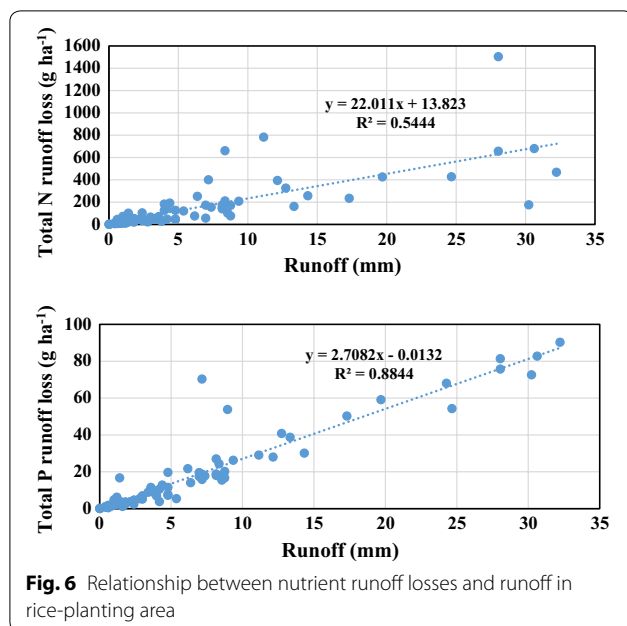
Fig. 5 Temporal changes in **a** runoff and **b, c** nutrient runoff losses in the rice-planting area

of the N loss loading throughout the year was lower than 400 g ha⁻¹. However, it increased sharply, i.e., reaching 1685.7 g ha⁻¹ from June 17 to September 4. The total P loss loading fluctuated greatly throughout the year, with 73.0% of the values lower than 20 g ha⁻¹ and 14.9% of the values higher than 40 g ha⁻¹, respectively. The total N and P runoff loss exhibited significant linear relationships with the runoff amount (Fig. 6, $p < 0.001$). The total N and P can be predicted with the runoff amount

following the equations: $y = 22.011x + 13.823$, $R^2 = 0.54$ and $y = 2.7082x - 0.0132$, $R^2 = 0.88$, respectively.

Abstract visualization and prediction of nutrient runoff loss by SOM approach

The abstract visualization of the relationships between the total N and P concentrations in the retention ditch and adjacent stream water samples as well as the SOM-obtained accumulated rainfall amounts at 6–48 h



intervals (i.e., H6–H48) before each water sampling event, is shown in Fig. 7. The results suggest that the high total P concentration in the rice-field drainage ($0.28 \mu\text{g L}^{-1}$) was a response to the low rainfall amounts at H6 (3.59 mm), H12 (6.02 mm), H18 (7.81 mm), H24 (9.18 mm), H36 (11.2 mm), and H48 (12.4 mm) (Fig. 7). Meanwhile, the high total N concentration in the rice-field drainage ($>2.5 \mu\text{g L}^{-1}$) was a response to the low rainfall amounts at H6 (<3.07 mm), H12 (<5.34 mm),

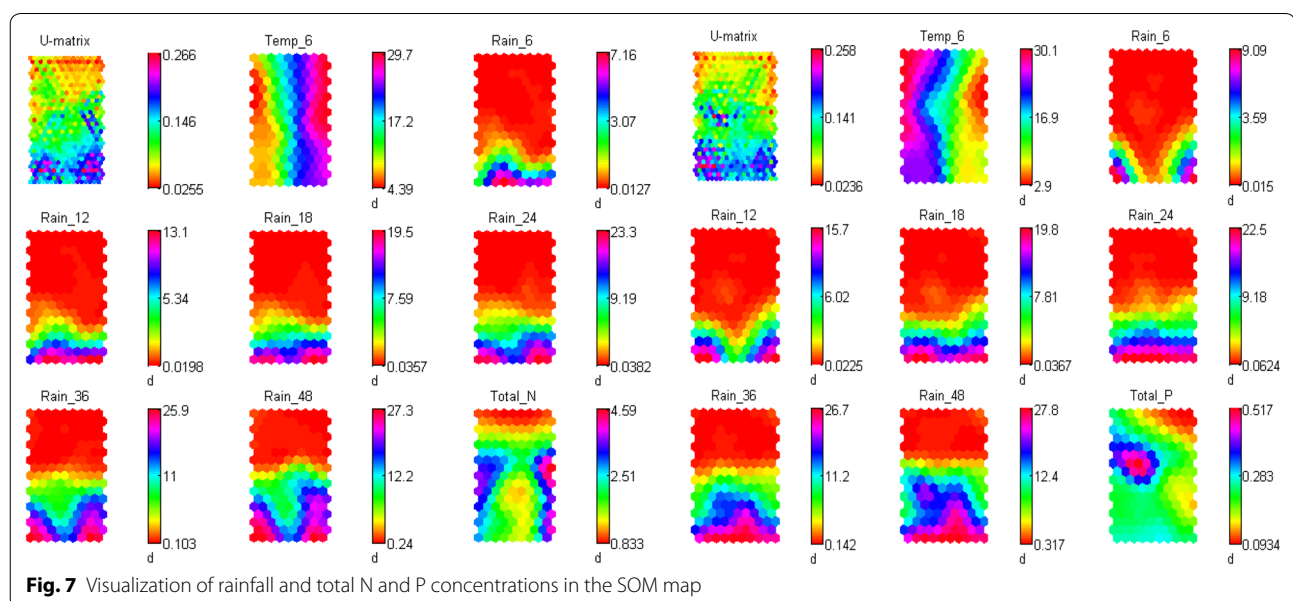
H18 (<7.59 mm), H24 (<9.19 mm), H36 (<11.0 mm), and H48 (<12.2 mm) (Fig. 7).

Discussion

We found that the window phase for the total N loss mainly appeared in the rice-growing season. However, the window phase for the total P loss was more dispersive, attributed to the different behavior of the total N and P in the runoff and the fertilizer management during the planting of rice. The demand for N in rice is much higher than that of P. In this experiment, N fertilizer (i.e., 186 kg N ha^{-1}) was applied to the soil on three occasions, mainly in July–August. However, P fertilizer (i.e., $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) was applied as a base fertilizer before rice planting.

Additionally, studies show that soil P has a much lower migration rate than soil N [38]. Some studies [39–41] confirm that N losses with both forms, i.e., organic nitrogen (Org-N) and nitrate ($\text{NO}_3\text{-N}$), are predominantly conditioned by the soil fertilization type, while P losses are mainly associated with soil particles, and the agricultural land uses at any intensity. Therefore, the window phase of total N is mainly concentrated in the rice-planting season following fertilization. Contrarily, the window phase of total P is relatively dispersed throughout the year, attributed to the surface runoff. The study showed that the peak flows in the window phase usually contained the majority of N and P loss [42, 43].

Meanwhile, the loss window phases of total N and P are consistent with the runoff pattern. When runoff occurs, higher total P loss loading also occurs (Fig. 5). However, the concentration does not show the same pattern. The



concentration of total P in the runoff during heavy rainfall periods (especially in the rice-planting season from June to July) is rather low. The low total P concentration may be due to the strong effect of P immobilization and the adsorption onto the soil [44]. Some studies [45] show that the total P in the paddy soil is mainly organic P and inorganic Al oxide-P and Fe oxide-P, which is wrapped in aggregates, and it is not easily released into the runoff. Some studies [46, 47] showed that P migrates mainly through small-sized organic-inorganic composite colloids. Therefore, its mobility is relatively less affected by runoff, and its concentration increases when soluble P and colloidal P enter the water body with an increasing runoff amount. During heavy rainfall, all the soluble P and colloidal P in the soils carried by the runoff, and the concentration is diluted, resulting in a lower concentration [47]. However, owing to the fertilization that occurs during the rice-planting period, the N concentration in the soil tends to be remarkably high, with a peak value consistent with the peak value of the heavy rainfall.

Moreover, the results of their study revealed that the total N and P concentrations in irrigation water have an impact on the drainage total N and P loads. However, the total N and P transport to the tile-drains was primarily regulated by the macropore flow and was not significantly affected by storms [4]. Furthermore, a study by van der Salm et al. [48] on the nutrient losses from a heavy clay soil in a fluvial plain in the Netherlands found that the contribution of pipe drains to the total discharge of N and P was strongly related to the length of the dry period in the preceding summer, attributed to the very low conductivity of the soil matrix and the formation of shrinkage cracks. Another study [49] reports that the total P concentration in the drainage flow is independent of the Olsen P, while the antecedent soil moisture had a strong influence on the total P loss in the drainage flow. Furthermore, higher concentrations were recorded above a certain soil moisture deficit threshold.

The Δ total N, in this study, showed negative values, while the Δ total P showed positive values. This finding indicates the role of the stream on total N and P at different periods. The field runoff or channel drainage often influences the stream water quality. A study by Tomer et al. [50] on runoff in the Tipton Creek watershed (Iowa) shows that the channel drainage dominated, and was an essential source of the total N and P discharge of the watershed. In the present study, total P concentrations were high in the water samples, especially in the water sample from the retention ditch. More than 75% of the drainage water samples had higher P concentrations than that stated in the United States Environmental Protection Agency (US EPA) guidelines (i.e., 0.10 mg total P L⁻¹ for streams) [51],

and more than 90% of the samples exceeded 0.02 mg total P L⁻¹. This value is a critical total P concentration value, above which the eutrophication in the surface water would accelerate [52]. These data indicate that the water monitoring and forecasting of the retention ditch are essential to protect the water quality of the adjacent streams.

The annual average N runoff from the paddy field was 11.6 kg ha⁻¹, which is consistent with the average loss loading of 12.7 kg ha⁻¹ confirmed by field-scale experiments [8, 53, 54]. The annual average P runoff from the paddy field was 1.5 kg ha⁻¹, which was higher than the 0.75 kg ha⁻¹ of total P by field-scale experiments in TaiHu region of China [17, 55]. Other field-scale studies [12, 18] found a higher P runoff, which ranged from 5.49 to 17.68 kg ha⁻¹. We also found that the total N and P loss loadings, rather than the concentrations of total N and P in the runoff, were linearly related to the surface runoff amount, which confirmed our hypothesis. This result shows that we can predict the loss loadings of total N and P using the cumulative runoff amount. As the total N and P concentrations fluctuate across the rice seasons, the total N and P loss loadings cannot be directly calculated as the product of the concentration and runoff at each time point. This relationship provides a simple tool for predicting the nutrient loss loading in the retention ditches of the paddy field. Consistent with our results, a study by Xue et al. [56] in the Baltic Region also shows no correlations between the nutrient concentrations and precipitation in the Mrzezino canal. Meanwhile, other studies [43] indicate the similarities in total P loss in the tile drainage and surface runoff, as well as the strong correlations between total P loss and storm hydrographs.

Using high-resolution monitoring at 6-h intervals, we found that the rainfall amount was an essential factor that affects the total N and P concentrations in the retention ditch. These findings are supported by the results of other studies that were conducted in eastern China and other Asian monsoon areas [57, 58]. However, the SOM showed weak relationships between the rainfall at 6, 12, 18, 24, 36, and 48 h intervals with the total N and P concentrations. Some studies using high temporal resolution monitoring (i.e., at 0.5 h intervals) show that using a 1-h sampling frequency may lead to a higher error in assessing the total pollution load than when using 0.5 h frequency [59]. However, determining whether this error is an over- or under-estimation depends on which 1-h sample set was used. This is also consistent with our result, which revealed that using more than 24 h monitoring data did not improve the relationship between the total N and P in the retention ditch and the accumulated rainfall amount than when using shorter monitoring periods, i.e., < 24 h.

In addition to the rainfall, there are many other factors, such as soil conditions (i.e., soil moisture, soil depth, soil macropore, available N and Olsen P concentrations) and management practices (i.e., irrigation N and P concentrations, dry period, land cover, and fertilization), that influence the drainage water N and P concentrations or loadings [4, 47, 60]. Therefore, future studies should consider such additional environmental and management factors in the SOM approach to improve prediction accuracy. The SOM approach, developed in this study, helps to predict the total N and P in the drainage based on high-resolution monitoring data, i.e., at 6-h intervals. This approach was easy to implement by river managers in designing a long-term protection plan to maintain the water quality; however, it may be unable to predict the daily total N and P concentrations based on the daily rainfall forecast. In the present study, we only investigated the total P and N in the drainage water. Other P and N forms, especially particulate, colloid, soluble, reactive, and unreactive P, NH_3^+ -N, and NO_3^- -N should be tested further because several studies have shown that their response to rainfall in storm events was much closer than that of the total P [4].

Conclusions

We found some significant window phases and dissipation periods for the runoff of total N and P in the large-scale observation system of the paddy field. However, the total N and P showed different patterns. Using high-resolution monitoring data at 6-h intervals, we found that there is a strong relationship between the runoff and total N and P losses from the paddy field. The high-resolution monitoring data enabled the establishment of the relationship between the rainfall and total N and P concentrations in the runoff; thus, it can be used to predict the daily total N and P loss potential and guide agricultural non-point source pollution control practices in the future. Future studies should incorporate other factors such as soil conditions and agricultural practices into the SOM approach for improving prediction accuracy.

Abbreviations

SOM: self-organizing maps; N: nitrogen; P: phosphorus; MASE: mean absolute scaled errors; Rd: runoff amount; Rf: rainfall; PP: particulate P.

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Authors' contributions

SH and FYL are the co-first authors of this article, XQL is the corresponding author and designed this study, SH, SW, YBJ, BYL, HL, GMT and FYL completed

the experiment and conducted data analysis. SH and FYL wrote the manuscript and had the primary responsibility for the final content. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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