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Decreased Internal Phosphorus Loading From Eutrophic Sediment After Artificial Light Supplement: Preliminary Evidence From a Microcosm Experiment

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Nutrient loading reduction is an essential approach for controlling eutrophication. In addition to external nutrient loading, internal phosphorus (P) loading is usually considered one of the most important factors determining nutrient levels in water. The underwater light climate plays a pivotal role. However, few studies have been reported on the effect of light intensity on P release, and the existing studies have not drawn a definitive conclusion on whether underwater light has a positive or negative effect on P release. To confirm the effect of underwater light on internal P release, a 1-month microcosm experiment was carried out (18 November–15 December 2020) under three light intensities. The P release flux (F_P) was significantly higher in the control (no light) group than in the low light group during the first 2 weeks ($p = 0.03$). No difference among treatments occurred for accumulative F_P in the past 4 weeks, although it tended to be higher in the control than in both the low and high light groups ($p > 0.05$). Spearman rank correlations showed that photosynthetic photon flux density (PPFD) was positively correlated with DO, pH, phytoplankton chlorophyll *a* (Chl a_{Phyt}) and benthic algae chlorophyll *a* (Chl a_{Bent}). DO was positively correlated with Chl a_{Phyt} and Chl a_{Bent}. The results indicate that light may promote the growth of phytoplankton and benthic algae, both of which may increase DO and pH. DO inhibits P release from sediment and pH promotes P release from sediment. Lake-scale studies are needed to fully evaluate its effect under natural conditions, as many other factors (e.g., wind or fish disturbance) in natural lakes could regulate P release from sediment.

Keywords: artificial light supplement system, Eutrophication, internal P loading, Phytoplankton, Periphyton

INTRODUCTION

Eutrophication of lakes is becoming a worldwide environmental problem caused by excess nutrient loading, e.g., phosphorus (P) and nitrogen (N) (Schindler, 1977; Schindler et al., 2008). The problems arising from eutrophication are the appearance of toxic algal blooms, death of submersed aquatic vegetation, fish kills, water quality deterioration and other serious environmental issues, which ultimately lead to hazards to public health (Smith, 2003; Gubelit and Berezina, 2010; Liu et al., 2016; Jeppesen et al., 2020; Wang et al., 2021). Controlling nutrient loading is essential for inhibiting eutrophication, especially P loading. However, in addition to external P loading, internal P release from sediment contributes substantial amounts of bioavailable P to overlying waters and is a considerable nutrient resource for the water column in eutrophic lakes (Søndergaard et al., 2001).

Internal P release is regulated by several environmental factors, such as temperature, pH, dissolved oxygen concentration (DO), and frequent hydrodynamic disturbances (Fan et al., 2001; Søndergaard et al., 2001; Li et al., 2013). Various measures have been applied to reduce the internal loading of P, including physical (dredging, *in situ* capping, etc.), chemical (chemical flocculants and synthetic materials) and biological (submerged macrophyte restoration) means (Zhang et al., 2021). Among physical methods, dredging can remove the nutrient-rich surface layer of sediment, which has been widely applied to control the internal nutrient loading of shallow lakes (Gustavson et al., 2008). The caps can form physical barriers on the surface of sediment mainly by spraying natural materials (sand, clay, gravel and rock), which effectively inhibit internal nutrient release. Chemical methods are often combined with physical barriers. Geoengineering materials act as solid phase P sorbents and have been widely used in many restoration practices, such as flocculants and phosphorus-locking materials (Wang et al., 2017; Yin et al., 2018; Jin et al., 2019; Yang et al., 2021).

Reestablishment of submerged macrophytes has become one of the most widely used methods in lake restoration considering their positive effect in maintaining a clear-water state. Submerged macrophytes have, but are not limited to, the capability to absorb nutrients and inhibit phytoplankton growth and sediment resuspension which may lead to decrease of internal P release (Hilt, 2006; Hilt and Gross, 2008; Zhang et al., 2016). In eutrophic lakes, impaired underwater light climate is one of the main factors hindering the growth of submerged macrophytes (Schelske et al., 2010; Zhang et al., 2016). Recently, artificial light-emitting diodes (LED) have been proposed as a potentially useful method for macrophyte reestablishment in eutrophic lakes. It has been confirmed that LED light supplementation can promote the growth rate of submerged macrophytes (Xu et al., 2019). Consequently, supplementation with artificial light can be a potentially useful approach for the restoration of eutrophic lakes. Some studies have found that artificial light supplementation could promote not only macrophyte growth (Grubisic et al., 2018) but also phytoplankton growth and then lead to internal P release by increasing alkaline phosphatase activity (APA) (Ma et al., 2018). However, few works have studied about the effects of light on internal P loading.

To study whether LED light can ultimately influence internal P loading under eutrophic conditions, a 1-month experiment with three light intensities was carried out in microcosms. The objectives of this study were to explore 1) the effect of LED light on P release from sediment and 2) the possible mechanism underlying the changes in P release under different light conditions. The results could provide a scientific basis for the control of internal P release in eutrophic lakes and may contribute to the development of the technology in lake restoration.

MATERIAL AND METHODS

Study Area and Experimental System Set-Up

The experiment was conducted in nine transparent Perspex tubes (inner diameter: 0.08 m; height: 1 m; volume: 5.0 L) at our field station near Lake Bao'an, which is located in the middle and lower Yangtze River Basin. Water (TN = 16.4 mg L^{-1}, TP = 0.8 mg L^{-1}) and sediment (TN_{Sed}, 4.96 g kg^{-1} dw; TP_{Sed}, 2.74 g kg^{-1} dw; OM_{Sed}, 43.87 g kg^{-1} dw) were collected in a hypertrophic urban lake—Lake Nanhu (Wuhan, China) (area: 7.67 km^2, N 30°29′10″, E 114°22′39″). According to a survey conducted in Lake Nanhu from August 2019 to April 2020, the annual mean Secchi depth (Z_{SD}) was 0.27 m, pH was 7.3, dissolved oxygen concentration (DO) was 8.4 mg L^{-1}, total phosphorus (TP) was 0.46 mg L^{-1}, and phytoplankton chlorophyll *a* (Chl a_{Phyt}) was 112.2 μg L^{-1} at half water depth. Sediment (0.2 m in height) were collected using transparent Perspex tubes. To avoid disturbing the sediment, well-mixed lake water was then slowly added to the tubes along the wall and adjusted to a height of approximately 0.8 m (**Supplementary Figure SA1**). The introduction of sediment and water was completed on 12 November 2020.

Experimental Treatments

A gradient of three light intensities (at the sediment-water interface of the tubes) with three replicates was set: control (0 μmol m^{-2} s^{-1}), low light (100 μmol m^{-2} s^{-1}), and high light (200 μmol m^{-2} s^{-1}). The light intensity in control group was near to 0 μmol m^{-2} s^{-1}, the lowest value can be seen in the field and also the real situation in many hypertrophic urban lakes, such as Lake Nanhu in Wuhan (China). The low light of 100 μmol m^{-2} s^{-1} corresponds to the light intensity at one half of the water depth in Lake Nanhu. The high light of 200 μmol m^{-2} s^{-1} corresponds to light saturation point of benthic algae (Hill et al., 1995). Lights (white, 380–780 nm) were provided by the Institute of Semiconductors, Chinese Academy of Sciences. The dark/light cycle was 12:12 h. The experiment lasted 28 days, from 18 November 2020 to 15 December 2020.

Sampling and Sample Analyses

The first survey was conducted on 18 November, 7 days after the introduction of sediment and water. Environmental parameters

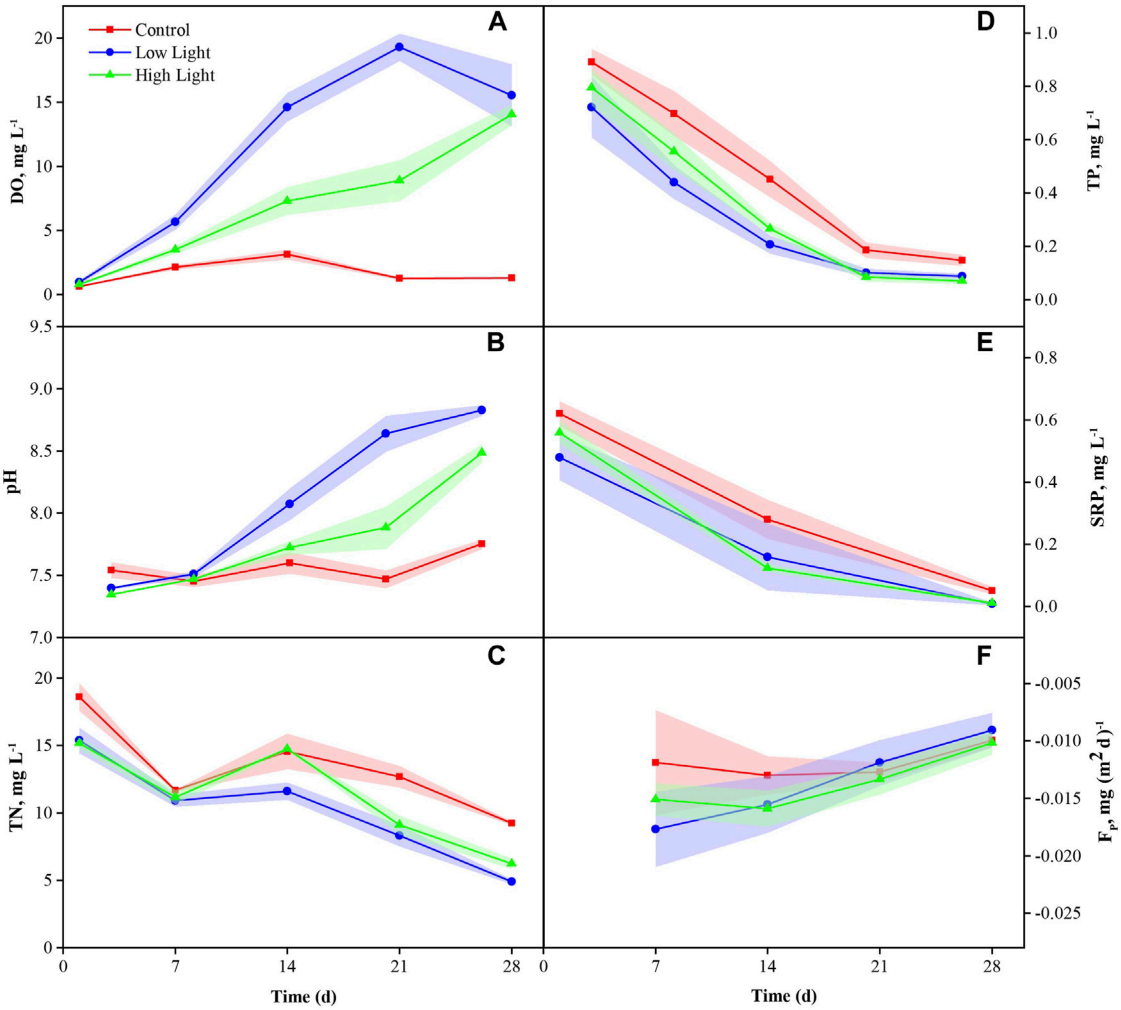

FIGURE 1 | Dissolved oxygen (DO) (mean ± SE) **(A)**, pH **(B)**, total nitrogen (TN) **(C)**, total phosphorus (TP) **(D)**, soluble reactive phosphorus (SRP) **(E)** and P release flux (F_P) **(F)** in various treatments during the experiment.

pH, dissolved oxygen concentration (DO) and water temperature (WT) were measured *in situ* at the bottom of the water with a YSI Pro Plus (Yellow Spring Inc., Yellow Springs, OH, United States) once every week. Light intensity was measured twice (before and after treatment) at the sediment-water interface using an illuminometer (LI-192SA, LI-COR, Lincoln, NE, United States).

Water samples were taken at three depths (0.2, 0.4, 0.6 m, the distance between the sediment surface and the water surface). Well-mixed water samples were brought to the laboratory for chemical analysis once a week. In order to reduce the interference of sampling on water and sediment, the process of sampling was not repeated. Total nitrogen (TN) was determined following an alkaline potassium persulfate digestion-UV spectrophotometric method (PERSEE, TU-1810, Beijing) (Huang et al., 1999). Total phosphorus (TP) in the water column was determined using an ammonium molybdate-ultraviolet spectrophotometric method after digestion with $K_2S_2O_8$ solution (PERSEE, TU-1810, Beijing) (Huang et al., 1999). Soluble reactive phosphorus (SRP) in the water column was measured using the molybdenum blue method (Murphy and Riley, 1962) with water filtered through 0.45 μm Millipore filter paper (Whatman, GE Health care UK Limited, Buckinghamshire, United Kingdom). Phytoplankton chlorophyll *a* (Chl a_{Phyt}) was extracted using 90% acetone (at 4°C for 24 h) after filtration through GF/C filters (Whatman, GE Health care UK Limited, Buckinghamshire, United Kingdom), and absorbance was then measured at 665 and 750 nm, both before and after acidification with 10% HCl using a spectrophotometer (PERSEE, TU-1810, Beijing) (Huang et al., 1999).

Pore-water samples of the surficial 10 cm sediment in each tube were collected once a week using a soil moisture sampler (SMS rhizons, Eijkelkamp, Giesbeek, Netherlands) and were subsequently filtered with a 0.45 μm cellulose acetate membrane to measure SRP (Murphy and Riley, 1962).

Surface sediment samples (0–0.1 m) were taken by a plexiglass corer (inner diameter: 0.08 m). The top layer (1 cm) of the samples was placed in 10 ml plastic tubes to measure the

TABLE 1 | The initial (18 November 2020) conditions of the experimental systems (mean ± SD).

	Control	Low light	High light
Photosynthetic photon flux density (PPFD), μmol m^{-2} s^{-1}	0.00 ± 0.00	121.17 ± 3.60	207.75 ± 22.09
Dissolved oxygen (DO), mg L^{-1}	0.62 ± 0.04	0.98 ± 0.25	0.80 ± 0.13
pH	7.54 ± 0.11	7.40 ± 0.02	7.35 ± 0.02
Water temperature (WT), °C	20.77 ± 0.06	20.70 ± 0.00	20.70 ± 0.00
Total phosphorus (TP), mg L^{-1}	0.89 ± 0.08	0.72 ± 0.20	0.79 ± 0.12
Soluble reactive phosphorus (SRP), mg L^{-1}	0.62 ± 0.07	0.48 ± 0.13	0.56 ± 0.07
Total nitrogen (TN), mg L^{-1}	18.59 ± 1.79	15.37 ± 1.66	15.14 ± 0.72
Phytoplankton chlorophyll *a* (Chl a_{Phyt}), μg L^{-1}	6.98 ± 1.89	3.94 ± 0.53	3.94 ± 1.05
Benthic algae chlorophyll *a* (Chl a_{Bent}), μg g^{-1}	1.23 ± 0.29	1.66 ± 0.25	1.30 ± 0.13

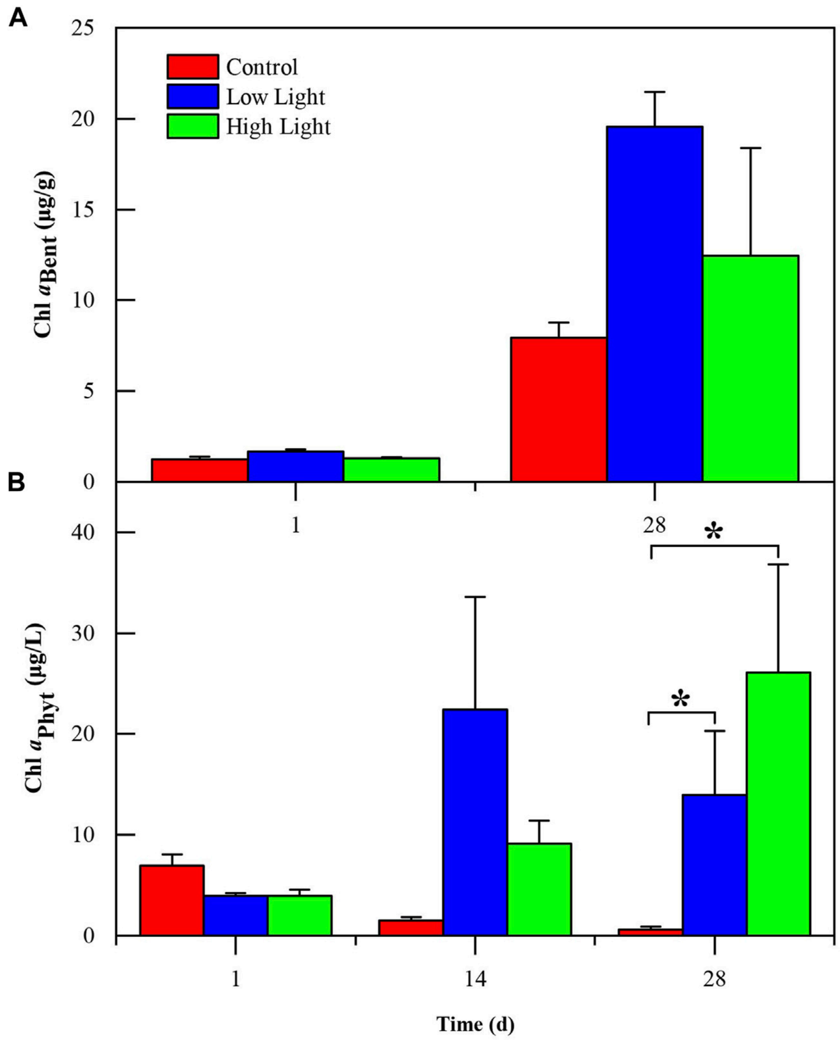

FIGURE 2 | Phytoplankton chlorophyll *a* (Chl a_{Phyt}) (mean ± SE) **(A)** and benthic algae chlorophyll *a* (Chl a_{Bent}) **(B)** in various treatments during the experiment. The label (*) indicates significant differences (p < 0.05) among treatments.

benthic algae chlorophyll *a* (Chl a_{Bent}). The samples were extracted with 7 ml of 90% acetone at 4°C for 24 h and then centrifuged for 10 min at approximately 4000 rpm. The absorbance at 665 and 750 nm, both before and after acidification with 10% HCl, was used to calculate Chl a_{Bent} using a spectrophotometer (PERSEE, TU-1810, Beijing) (Huang et al., 1999; Boer et al., 2009).

Phosphorus release flux was calculated by comparing TP concentrations in overlying water (Boström and Pettersson, 1982; Nürnberg and Gertrud, 1987).

$$F_P = M * A^{-1} * T^{-1} \quad (1)$$

$$M = \sum V_t (C_t - C_{t-1}) \quad (2)$$

where F_P is the phosphorus release flux (mg $(m^2\ d)^{-1}$), M is the variation in phosphorus with time t (mg), T is the days to calculate F_P (d), V_t is the volume of overlying water with time t (L), A is the area of the sediment-water interface (m^2), and C_t and C_{t-1} are the TP concentrations in water at t and t−1, respectively (mg L^{-1}). **Equation 1** represents the cumulative effect through calculating Fp.

Statistical Analyses

R 4.0.3 and OriginPro 2021 were used to process and analyze the data. Spearman rank correlations were applied to test the relationships between environmental parameters using R 4.0.3. Regression analysis were used to test the effect of photosynthetic photon flux density (PPFD) on F_P. These two analyses are commonly used to study the relationship between variables in statistics. They can determine that two sets of variables have statistical correlation. The difference is that regression analysis can quantitatively obtain the relationship between the two variables, one of which can be regarded as a cause and the other as a result. To determine the difference between treatments, a Friedman test (F-test) was conducted using R. Wilcoxon-Nemenyi-McDonald-Thompson post-hoc test was used when the Friedman test gave a significant p value (<0.05).

RESULTS

Variation in Environmental Factors

The initial water quality parameters differed very little among treatments (**Figure 1**). PPFD among the treatments showed a clear gradient, which was highest in the high light (207.75 ± 22.09 μmol $m^{-2}\ s^{-1}$), followed by low light (121.17 ± 3.6 μmol $m^{-2}\ s^{-1}$) and control (0.00 ± 0.00 μmol $m^{-2}\ s^{-1}$) (p = 0.05), as expected (**Table 1**).

DO showed a significant difference among the treatments (p < 0.01) on the 14th day of the experiment, being significantly higher in the low light and high light groups than in the control (p = 0.03). On the 28th day, DO showed a pattern like the previous 2 weeks, being significantly higher in the low light and high light groups than in the control (p = 0.03) (**Supplementary Table SA1**; **Figure 1A**).

The pH showed no significant differences among the treatments in the first 2 weeks (p > 0.05), while a significant difference was discerned between the low light and high light groups, being significantly higher in the low light group than in the control (p = 0.05). On the 28th day, the pH was significantly higher in the low light and high light groups than in the control (p < 0.01) and was significantly higher in the low light group than in the high light group (p < 0.01) (**Supplementary Table SA1**; **Figure 1B**).

The low light and high light groups had similar Chl a_{Phyt} (p = 0.75), both were significantly higher than that in the control group (p = 0.03) (**Supplementary Table SA1**; **Figure 2B**). No difference was found in Chl a_{Bent} in any treatment (p = 0.37) (**Supplementary Table SA1**; **Figure 2A**).

Variation in Phosphorus Variables

For TP in the water column, both the low light and high light groups showed no significant difference, and both were significantly lower than the control (p < 0.05) (**Supplementary Table SA1**; **Figure 1D**). TN in the water column showed a similar pattern (p < 0.05) (**Supplementary Table SA1**; **Figure 1C**). The SRP in the water column showed no significant differences among the treatments in the first 2 weeks (p > 0.05). In the last week, the SRP was significantly higher in the control group than in the high light group (p < 0.03) (**Supplementary Table SA1**; **Figure 1E**).

F_P showed no significant differences among the treatments in the first 2 weeks (p > 0.05), while a significant difference was discerned between the control and low light groups, being significantly higher in the control than in the low light group (p = 0.03). No difference of accumulative F_P among treatments occurred in the past 4 weeks, although it tended to be higher in the control group than in the low light and high light groups (p > 0.05) (**Supplementary Table SA1**; **Figure 1F**).

Relationships of PPFD With Phosphorus Variables and Influencing Factors

Spearman rank correlation showed that DO, pH, Chl a_{Phyt} and Chl a_{Bent} were positively correlated with PPFD. PPFD was significantly positively correlated with Chl a_{Phyt} (p = 0.03) (**Supplementary Table SA2**; **Figure 3**). TP, SRP and TN were negatively correlated with PPFD. PPFD was significantly negatively correlated with TP and SRP (p < 0.05) (**Supplementary Table SA2**; **Figure 3**). In the scatterplots, PPFD has a significantly positive regression with DO, pH and Chl a_{Phyt} and a significantly negative regression with TP, SRP and TN (p < 0.05) (**Figure 4**).

Relationships of Influencing Factors With Phosphorus Variable

Spearman rank correlation showed that SRP were significantly positive correlated with TN and a significantly negative correlation with DO, pH and Chl a_{Phyt} (p < 0.05) (**Supplementary Table SA2**; **Figure 5**). TP and SRP were negatively correlated with Chl a_{Bent}. There were no significant relationships between F_P and PPFD, DO, Chl a_{Bent}, Chl a_{Phyt} and TN (p > 0.05) (**Supplementary Table SA2**; **Figure 3**). In the scatterplots, TP has a significantly negative regression with DO and pH and a significantly positive regression with TN, which was the same as SRP (p < 0.05) (**Figure 5**). In addition, there was a significantly negative regression between SRP and Chl a_{Phyt} (p < 0.05) (**Figure 5**).

DISCUSSION

In our 1-month experiment with gradient artificial light supplementation, artificial light inhibited internal P release in at least the first 14 days. F_P was lower in the treatments with light from LEDs, even though only a significant difference was

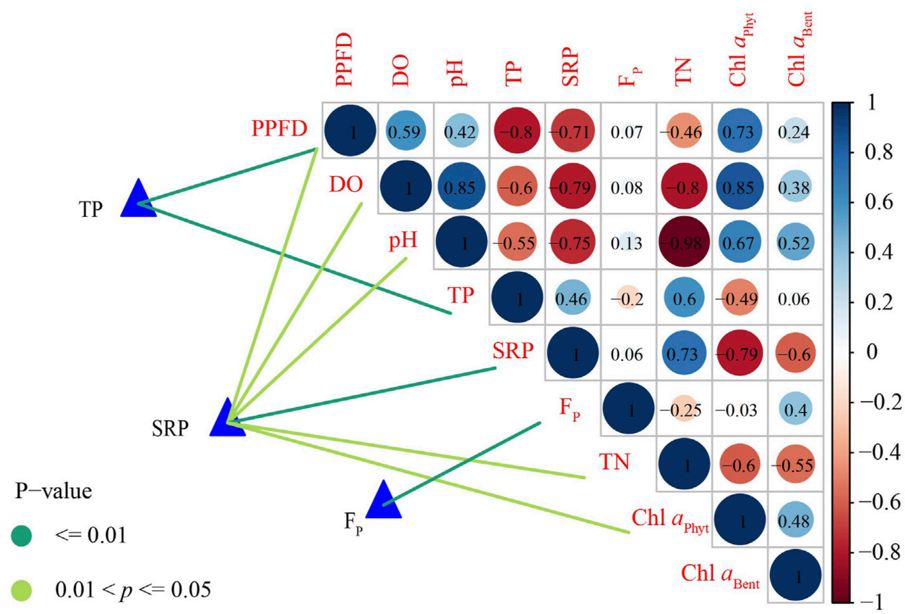

FIGURE 3 | Spearman rank correlation of phosphorus variables with environmental factors (blue: positive correlation; red: negative correlation; color shade and circle size: proportion to correlation coefficient; number: correlation coefficient). Total phosphorus (TP), soluble reactive phosphorus (SRP) and P release flux (F_P) were related to each environmental factor by Mantel tests (edge color denotes statistical significance) (PPFD, photosynthetic photon flux density; DO, dissolved oxygen; TN, total nitrogen; Chl a_{Phyt}, phytoplankton chlorophyll *a*; Chl a_{Bent}, benthic algae chlorophyll *a*).

discerned between the control and low light groups ($p = 0.03$) in the first 14 days. TP and SRP declined significantly with increasing PPFD, although they decreased in all treatments with time, which might indicate that our experimental systems favor the settlement of suspended particles (Schindler, 1998) (**Figure 4E**; **Figure 4F**). The results demonstrated that the addition of light from LEDs can inhibit sediment P release. Wang and Pei (2013) reported that the absence of light can significantly increase the SRP concentrations, which increased from 0.013 mg L^{-1} (10 days) to 0.021 mg L^{-1} (30 days). Similar patterns were found in dissolved total phosphorus (DTP), and the concentration of DTP under dark conditions was approximately eight times that under light conditions (Jiang et al., 2008). However, it was also reported in previous studies that illumination can increase PO_4^{3-} because of photocatalysis (Zhang et al., 2019; Li X. et al., 2017), which increased from 0.31 mg L^{-1} to 0.41 mg L^{-1} after illumination (Li X. et al., 2017). These findings suggested that photocatalysis can change organic phosphorus into available phosphorus. However, there was less organic phosphorus in our experimental system, so the photocatalytic effect was weak.

In aquatic ecosystems, algae can generate O_2 via photosynthesis under light conditions, which would reduce P release. O_2 oxidizes Fe^{2+} into Fe^{3+}, which easily combines with phosphorus to form a stable state, thereby reducing P release (Carlton and Wetzel, 1988; Hemond and Lin, 2010). In our experiment, Chl a_{Phyt} was 14 times greater in the low light and 26 times greater in the high light than that in the control at the end of the experiment ($p = 0.75$) (**Supplementary Table SA1**; **Figure 2A**). Chl a_{Bent} followed the same pattern as Chl a_{Phyt}, which was 2.5 times greater in the low light and 1.6 times greater in the high light than in the control at the end of the experiment (**Supplementary Table SA1**; **Figure 2B**). DO in the low light was 12 times greater and in the high light was 11 times greater than in the control and was significantly higher in the low light than in the high light on the 14th day of the experiment ($p < 0.01$) (**Supplementary Table SA1**; **Figure 1A**). TP and SRP showed a significant negative correlation with DO ($p < 0.05$) (**Supplementary Table SA2**; **Figure 3**). According to correlation analysis, the increase in DO caused by the growth of benthic algae and phytoplankton under light conditions might be one of the reasons for inhibiting sediment P release in our study.

Photosynthesis of algae produce O_2 and OH^- and elevate pH, which might regulate sediment P release (Zhang and Sun, 2004). P speciation according to binding forms includes the NaOH-P (P bound to metal oxides) and the HCl-P (consist mainly of apatite P) (Jin et al., 2006). pH influences chemical processes, such as NaOH-P release under alkaline conditions (pH > 8), HCl-P release under acidic conditions (pH < 6) while no sediment P release under neutral conditions (pH ≈ 7) (Jin et al., 2006; Li et al., 2013). In this study, pH was significantly higher in the low light group (pH = 8.8) than in the high light group (pH = 8.5) ($p < 0.01$) (**Supplementary Table SA1**; **Figure 1B**). The pH was positively correlated with Chl a_{Phyt} and Chl a_{Bent} even though not significantly ($p > 0.05$) (**Supplementary Table SA2**; **Figure 3**). F_P showed a significant positive correlation with pH ($p < 0.05$). The results suggested that the increased pH in the light treatment might promote internal P release.

The concentrations of SRP declined significantly with increasing Chl a_{Phyt} ($p = 0.05$) (**Figure 5I**), which may promote sediment P release. The above results showed that

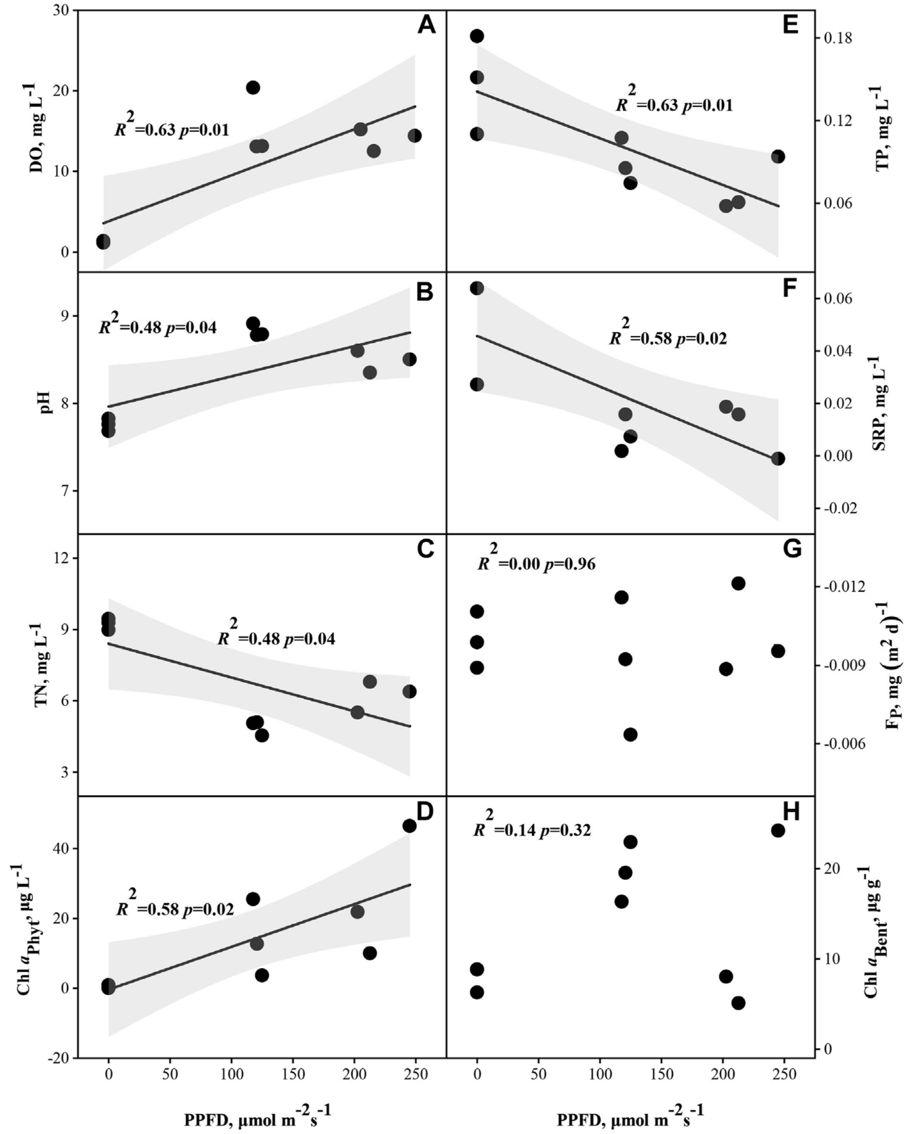

FIGURE 4 | Relationships between photosynthetic photon flux density (PPFD) and dissolved oxygen (DO) (n = 9) **(A)**, pH **(B)**, total nitrogen (TN) **(C)**, total phosphorus (TP) **(E)**, soluble reactive phosphorus (SRP) **(F)**, P release flux (F_P) **(G)**, phytoplankton chlorophyll *a* (Chl a_{Phyt}) **(D)** and benthic algae chlorophyll *a* (Chl a_{Bent}) **(H)**.

increasing light intensity may increase the uptake of phosphorus by algae in the surrounding environment, resulting in a decrease in the concentrations of SRP in water and an increase in the phosphorus concentration gradient at the water-sediment interface, thereby increasing the upward diffusion of sediment P to overlying water (Xie et al., 2003).

In aquatic ecosystems, microbial activity significantly affects sediment P release, in which bacteria can directly promote sediment P release through decomposition (Petterson, 1998). Algae and bacteria may promote P release by increasing APA which could decompose organic P into PO_4^{3-}, which provides the required P for the growth of algae and then promote internal P release (Ma et al., 2018). The increased Chl a_{Phyt} and Chl a_{Bent} in light treatments indicated the possible positive effect of APA on P release in this study. Photodegradation is also one of the possible factors that promotes sediment P release, which converts organic P into available P with direct and indirect conversion (Li X. et al., 2017). The direct decomposition of organic P under light is determined by its structure and morphology and the indirect decomposition of organic P into PO_4^{3-} by reactions with reactive oxygen species (ROS) (Nowack, 2003). In this study, APA and photodegradation were not measured, while light supplement finally decreased sediment P release through several combination approaches.

Our 1-month microcosm results suggest that light might inhibit sediment P release by promoting the growth of phytoplankton and benthic algae and improving the oxidation conditions in the sediment, and phosphorus inhibition effect of

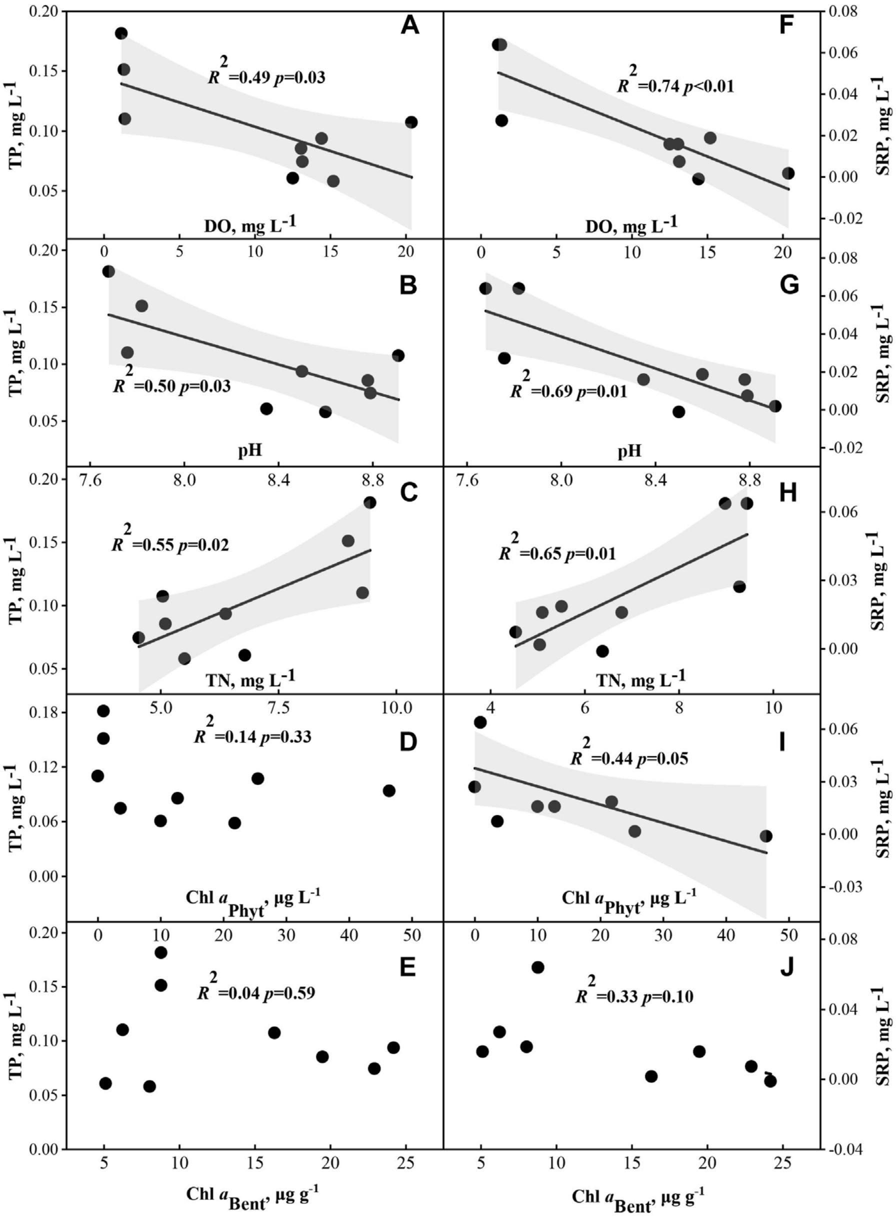

FIGURE 5 | Relationships between phosphorus variables (total phosphorus (TP) **(A–E)**; soluble reactive phosphorus (SRP) **(F–J)**) and dissolved oxygen (DO) (n = 9), pH, total nitrogen (TN), phytoplankton chlorophyll a (Chl a_{Phyt}) and benthic algae chlorophyll a (Chl a_{Bent}).

100 μmol m^{-2} s^{-1} (low light treatment) was better than 200 μmol m^{-2} s^{-1} (high light treatment). Therefore, it is feasible to control sediment P release by artificial light supplementation in the ecological restoration of eutrophic lakes. However, our study has some limitations: 1) such small experimental system was unable to simulate the sediment resuspension caused by biotic (fish, crab, etc.) and abiotic (wind, hydrodynamic, etc.) factors in a natural lake; 2) this study set up a limited light intensity gradient. There were three light gradients in our experiment (0, 100, and 200 μmol m^{-2} s^{-1}), and low light was the best among the three light intensities. However, the threshold of light intensity for inhibiting sediment P release remains to be verified; 3) the mechanism underlying the changes in P release under different light conditions remains to be futher studied. In sum, the feasibility of LED light supplementation needs further exploration in larger-scale experimental systems or field studies.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

MZ, YL, H-JW, and H-ZW designed the research. MZ, Y-XY, J-HL, R-TQ, and ML carried out the research. MZ, YL, H-JW, and H-ZW performed the data analyses. MZ and YL prepared the original draft of the paper. H-JW, H-ZW, and S-NM commented on the various drafts.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.801469/full#supplementary-material

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