The Effect of Warming-Amplified Phosphorus Addition on a Peatland’s N$_2$O Emissions

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Abstract: Natural montane peatlands are generally not a significant source of nitrous oxide (N$_2$O) due to environmental limitations, including phosphorus (P) scarcity and temperature lowness. Phosphorus enrichment and warming caused by global change are altering these limitations, and are likely to increase the source function of N$_2$O. However, the combined effects of P addition and warming on N$_2$O fluxes and biotic/abiotic factors in peatlands are still uncertain. To address this, we investigated the long-term (12 yrs) effects of P addition (5 and 10 kg ha$^{-1}$ yr$^{-1}$) and its interaction with warming on N$_2$O fluxes in a peatland. The results showed that although long-term P addition did not significantly affect the source/sink function of N$_2$O in the peatland, it stimulated enzyme activities and promoted peat decomposition. However, warming amplified the effect of P addition to increase N$_2$O emissions by stimulating enzyme activities and changing soil stoichiometry, so even turned the peatland into a significant source of N$_2$O with an emission of approximate 100 g m$^{-2}$ during the growing season. Our study suggests that P enrichment against the current background of global warming will enhance the possibility of strong N$_2$O emissions in montane peatlands, which may increase the risk that global warming will be further aggravated.

Keywords: nitrous oxide emissions; enzyme activities; montane peatland soils; global change; long-term effect

1. Introduction

Nitrous oxide (N$_2$O) is an important greenhouse gas with a warming potential 273 times that of carbon dioxide (CO$_2$) [1]. Montane peatlands are huge nitrogen (N) pools, but not a significant source of N$_2$O emissions due to phosphorus (P) limitations and low temperature [2–7]. However, the increase in P deposition and continuous warming caused by global changes will change the current status of peatlands, which may increase the possibility of peatlands being a hotspot of N$_2$O emissions [8–10]. Nevertheless, the underlying mechanism that influences the response of N$_2$O emissions and biotic/abiotic factors in peatlands to the interaction of P addition and warming has rarely been studied.

Phosphorus is limited in 43% of the global land soil [11,12], and it is also a key factor for controlling N$_2$O emissions in peatlands [13]. However, the continuous intensification of human activities and the availability of P increase have resulted in P no longer being the limiting factor for ecological processes in peatlands [14–17]. Increased P input will stimulate the activity of nitrifying and denitrifying bacteria, accelerate N turnover in soil, and promote
soil N mineralization, which may produce more N\textsubscript{2}O [3,18–21]. Mori’s meta-analysis found that the addition of P to a P limited ecosystem will meet the microbial demand for P, leading to a boom of microorganisms [22]. Li’s study showed that P addition can stimulate soil enzyme activities, which will promote peat decomposition and accelerate the cycling of C and N, thereby providing energy and substrates for nitrifying and denitrifying microorganisms, and promoting N\textsubscript{2}O emissions in boreal peatlands [7,23].

In addition to directly affecting microorganisms and enzyme activities, P addition can also desorb available C from the soil surface, such as dissolved organic carbon (DOC), providing substrates for microorganisms, stimulating nitrification and denitrification and promoting N\textsubscript{2}O emissions [24,25]. Phosphorus addition even increases microbial activity in non-P limited soil, which may increase N\textsubscript{2}O emissions [26]. This indicates that P addition does not only alleviate microbial P limitations, but also increases N\textsubscript{2}O emissions through abiotic C transfer [27].

Global peatlands are gradually shrinking in some areas due to climate change and anthropic disturbance [28]. With the current global warming, the sink function for the greenhouse gases CO\textsubscript{2} and N\textsubscript{2}O in peatlands will be severely weakened due to changes in vegetation composition and the acceleration of peat decomposition [29]. Warming will also stimulate soil enzyme and microbial activities, and directly or indirectly promote N\textsubscript{2}O emissions from peatlands [10,30,31]. Phosphate monoesters and orthophosphates were the dominant forms of P in wetlands [32]. Warming will promote the transformation of stable P into unstable P [33], accelerate soil P cycling, and break the P limitation in the surface soil, leading to a clear increase in P availability in wetlands [34,35].

Currently, we still know rather little about how N\textsubscript{2}O emissions respond to joint environmental changes, P addition and warming, in wetlands, especially peatland ecosystems [18,21,35]. To address this, we conducted a field monitoring experiment in Hani peatland that was combined with laboratory experiments to investigate the effect of P addition, as well as its interaction with warming on peatland net N\textsubscript{2}O fluxes and the response of N\textsubscript{2}O fluxes to changes in biological and abiotic factors. We hypothesized that: (1) P addition would alleviate P limitation, stimulate soil enzyme activities, accelerate peat decomposition, provide reaction substrates and energy sources for the biochemical process of producing N\textsubscript{2}O, and lead to an increase in the net N\textsubscript{2}O fluxes in the peatland, and also that when more P was added, more N\textsubscript{2}O would be emitted; and (2) warming would amplify the facilitative effect of P addition on N\textsubscript{2}O emissions, and turn the peatland into a significant source of N\textsubscript{2}O.

2. Materials and Methods

2.1. Study Site

Hani peatland (126°31’ E, 42°13’ N), located in the Changbai Mountains, is one of the largest peatlands in Northeast China, with an altitude of 900 m and an average peat depth of 4 m [36]. The mean annual temperature is 3°C and the mean annual precipitation is 800 mm. The vegetation in the peatland is dominated by peat mosses (such as Sphagnum magellanicum Brig., S. imbricatum Hornsch. ex Russow etc.) and vascular plants (such as the shrub Betula ovalifolia Rupr. and the graminoid Carex lasiocarpa Ehrh.) [37].

2.2. Experimental Design

The field measurements were conducted at a 12 yr global change simulation experiment platform (established in 2007) of Hani peatland during the 2019 growing season (May to September). We selected 20 plots (0.8 m × 0.8 m), including five treatments (CK (control), P1 (5 kg P ha\textsuperscript{-1} yr\textsuperscript{-1}), P2 (10 kg P ha\textsuperscript{-1} yr\textsuperscript{-1}), P1W (P1 + Warming), and P2W (P2 + Warming)), each with four replicates. We used NaH\textsubscript{2}PO\textsubscript{4}·2H\textsubscript{2}O as the P fertilizer, dissolved it in 300 mL water, and evenly sprayed in plots once a month during the growing season. The same amount of distilled water was sprayed in CK plots. A boardwalk was built around the plots to reduce disturbance during the collecting of gas samples. The warming was passively achieved by the open top chamber (OTC, 0.8 m × 0.8 m at the top
and 1.2 m × 1.2 m at the bottom), which increased the air temperature by about 0.6 °C during the growing season (Figure S1). For more information, see Bu, et al. [37]; Yi, et al. [30]; and Lu, et al. [6].

2.3. Collection and Analysis of N$_2$O

The N$_2$O fluxes were measured eight times (twice in May, July, and September and once in June and August) by the static chamber-gas chromatography method. Gas samples (60 mL) were collected by a syringe from the static chamber at 10-min intervals over a 30-min period (0, 10, 20 and 30 min) and then measured by utilizing the electron capture detector (ECD) of gas chromatography (GC system, Agilent 7980B, Santa Clara, CA, USA) to calculate the concentration of N$_2$O; we also determined the N$_2$O flux by establishing a regression equation for gas concentration and sampling time (more details in Yi, Lu and Bu [30]).

2.4. Environmental Factors

Environmental factors of each plot were measured while monitoring N$_2$O fluxes, including soil temperature at 5 cm and 20 cm below the moss surface, air temperature at 20 cm above the moss surface, soil humidity (SM), water table depth (WTD), and pH of peat water in situ. The plant covers, including Sphagnum, vascular plants, and then total plant cover, were estimated by visual inspection at the end of July 2019 [38]. More details can be seen in Yi, Lu and Bu [30].

2.5. Water and Soil Sampling

In August 2019, peat samples were collected from plots and analyzed for their physicochemical indices, including total nitrogen (TN), total carbon (TC), total phosphorus (TP), and DOC [30].

2.6. Determination of Soil Enzyme Activities

β-D-glucosidase (BDG), N-acetyl-β-glucosaminidase (NAG) and phosphatase (PHO) are three types of hydrolytic enzymes highly related to the decomposition of organic carbon in peatlands [39–41]. The former three enzymes can hydrolyze cellulose into glucose, decompose chitin and catalyze phosphate monoesters to increase C, N and P availability for microorganisms and plants, respectively. Phenol oxidase (POX) can partially oxidize phenolic substances into simple organic compounds, and the activity of POX is crucial for the accumulation of organic matter in peatlands [42,43]. The microporous plate fluorescence method was used to determine the activities of the above three hydrolases and one oxidase in peat soil [6,44].

2.7. Statistical Analysis

The data were checked by the normality test before analysis, and logarithmic transformation was performed when needed. The effects of P addition, and the interaction of P addition and warming with mean N$_2$O fluxes during the growing season were analyzed by repeated measures analysis of variance (ANOVA). We used two-way ANOVAs to analyze the effects of P addition and its interaction with warming on N$_2$O fluxes and biotic/abiotic factors. One-way ANOVA was used to analyze the influences of different treatments on biotic/abiotic factors. We used the t-test to evaluate the significant difference between N$_2$O fluxes and zero, and Tukey’s HSD method was used to test the differences between treatments. Pearson correlation was used to assess the relationships between N$_2$O fluxes and biotic/abiotic factors, as well as the correlation between biotic and abiotic factors. We used principal component analysis (PCA) to assess the effects of different treatments on fluxes and biotic/abiotic factors. Structural equation modeling (SEM) was used to establish the relationships between all biotic/abiotic factors. All statistical analyses were performed in R 4.1.4 [45].
3. Results

3.1. \( \text{N}_2\text{O} \) Fluxes

Both low and high levels of P addition alone did not have a significant impact on the \( \text{N}_2\text{O} \) source and sink function of Hani peatland (Figure 1, Table 1). The plots with low levels of P addition tend to emit \( \text{N}_2\text{O} \) \((38 \pm 24 \text{ g m}^{-2}, t = 1.548, p = 0.219)\), while those with high levels of P addition tend to absorb \( \text{N}_2\text{O} \) \((-39 \pm 49 \text{ g m}^{-2}, t = 0.763, p = 0.484)\). Phosphorus addition with warming had a marginal effect on the cumulative \( \text{N}_2\text{O} \) flux during the growing season \((p = 0.121, \text{Table 1})\), but had a significant impact on the mean \( \text{N}_2\text{O} \) flux \((p = 0.010, \text{Table 1})\). Low levels of P addition combined with warming did not have a significant impact on the mean/sink function of \( \text{N}_2\text{O} \) in the peatland, while high levels of P addition under warming significantly promoted \( \text{N}_2\text{O} \) emissions \((t = 3.361, p = 0.041)\) (Figure 1), with a flux of \(101 \pm 30 \text{ g m}^{-2}\).

![Figure 1](image)

**Figure 1.** Cumulative \( \text{N}_2\text{O} \) fluxes \((\text{mean} \pm \text{stand error (SE),} n = 4)\) in Hani peatland in the growing season of 2019. CK, control; P1, P addition with 5 kg P ha\(^{-1}\) yr\(^{-1}\); P2, P addition with 10 kg P ha\(^{-1}\) yr\(^{-1}\); P1W, P1 + warming (0.6 °C); P2W, P2 + warming. Asterisks denote \( \text{N}_2\text{O} \) flux significantly different from zero. * \( p < 0.05 \); ns, no significant difference. Different colors are used to distinguish different treatments and making it more intuitive.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dynamic Fluxes</th>
<th>Cumulative Fluxes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( df ) ( F )</td>
<td>( P )</td>
</tr>
<tr>
<td>Warming</td>
<td>1</td>
<td>0.181</td>
</tr>
<tr>
<td>P addition</td>
<td>2</td>
<td>0.003</td>
</tr>
<tr>
<td>Warming ( \times ) P addition</td>
<td>2</td>
<td>7.658</td>
</tr>
</tbody>
</table>

Note: \( ** p \leq 0.01 \).

3.2. Abiotic Factors

WTD was significantly reduced after P addition (Table 2, Figure 2a), but in P1W plots it was significantly higher than in other treatment plots \((p < 0.007)\) (Figure 2a). Phosphorus addition alone significantly increased DOC concentration \((\text{P1}: p < 0.08, \text{P2}: p < 0.001)\) (Figure 2b), and DOC concentration in P2 plots was the highest among the five treatments \((p < 0.09)\), approximately twice as much as CK. DOC in P1W treatment was not significantly different from in CK, while it was significantly higher in P2W plots than in CK \((p < 0.05, \text{Figure 2b})\). There was no significant difference of TN concentration among different treatments, but TN was lowest in CK plots, and highest in P2W plots (Figure 2d). Phosphorus
addition, in isolation or in combination with warming, tended to increase TP concentration in peat water (Table 2, Figure 2e). In addition, there was no significant difference in TC concentration or pH among different treatments (Figure 2c,h). There was no significant difference in N:P ratio and C:N ratio between different treatments but these two indices showed a decreasing trend with combined P addition and warming (Figure 2f,g).

Table 2. Direct and warming interaction-mediating effect of P addition on environmental factors in Hani peatland (two-way ANOVA).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Warming</th>
<th>P Addition</th>
<th>Warming × P Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>$T_{\text{soil}}, 5 \text{ cm}$</td>
<td>1.748</td>
<td>0.206</td>
<td>0.325</td>
</tr>
<tr>
<td>$T_{\text{soil}}, 20 \text{ cm}$</td>
<td>5.396</td>
<td>0.034 *</td>
<td>0.3558</td>
</tr>
<tr>
<td>WTD</td>
<td>4.515</td>
<td>0.050 *</td>
<td>8.386</td>
</tr>
<tr>
<td>DOC</td>
<td>0.052</td>
<td>0.822</td>
<td>26.020</td>
</tr>
<tr>
<td>pH</td>
<td>0.140</td>
<td>0.713</td>
<td>2.219</td>
</tr>
<tr>
<td>TN</td>
<td>6.763</td>
<td>0.020 *</td>
<td>1.621</td>
</tr>
<tr>
<td>TC</td>
<td>1.899</td>
<td>0.188</td>
<td>1.707</td>
</tr>
<tr>
<td>TP</td>
<td>19.812</td>
<td>0.000 **</td>
<td>17.754</td>
</tr>
<tr>
<td>N:P</td>
<td>11.052</td>
<td>0.005 **</td>
<td>18.979</td>
</tr>
<tr>
<td>C:N</td>
<td>5.396</td>
<td>0.034 *</td>
<td>2.256</td>
</tr>
</tbody>
</table>

Note: WTD, water table depth; DOC, dissolved organic carbon; TN, total nitrogen; TC, total carbon; TP, total phosphorus. Asterisk represents a significant difference, **p < 0.01, *p ≤ 0.05.

Figure 2. Abiotic factors among the different treatments in Hani peatland in 2019 (mean ± SE, n = 4). (a) WTD; (b) DOC; (c) TC; (d) TN; (e) TP; (f) C:N; (g) N:P; (h) pH. CK, control; P1, P addition with 5 kg P ha$^{-1}$ yr$^{-1}$; P2, P addition with 10 kg P ha$^{-1}$ yr$^{-1}$; P1W, P1 + warming (0.6 °C); P2W, P2 + warming. WTD, water table depth; DOC, dissolved organic carbon; TC, total carbon; TN, total nitrogen; TP, total phosphorus. Different lower-case letters represent significant differences (p < 0.05) between the treatments. Different colors are used to distinguish different treatments and making it more intuitive.
3.3. Vegetation

Phosphorus addition significantly reduced Sphagnum cover but increased vascular plant cover ($p < 0.009$, Figure 3). However, no interactive effect of warming and P addition on total plant cover was observed ($p > 0.05$). No significant difference in total plant cover among treatments under P addition was found (Figure 3).

![Figure 3. Plants cover (mean ± SE, $n = 4$). CK, control; P1, P addition with 5 kg P ha$^{-1}$ yr$^{-1}$; P2, P addition with 10 kg P ha$^{-1}$ yr$^{-1}$; P1W, P1 + warming (0.6 °C); P2W, P2 + warming. Different capital letters represent significant differences between different treatments of the same plant cover, and different lower-case letters represent significant differences between different plants under the same treatment. $p < 0.05$.](image)

3.4. Enzyme Activities

Almost all enzyme activities were promoted under warming conditions. There was no significant difference in BDG, NAG and POX activities among the treatments with P addition and they were all higher than CK ($p < 0.05$ for all, Figure 4a,b,d). The PHO activity in the treatment with P addition was significantly lower than that in CK ($p < 0.001$), but increased with P addition (Figure 4c).

![Figure 4. Soil enzyme activities (mean ± SE, $n = 4$). (a) BDG; (b) NAG; (c) PHO; (d) POX. CK, control; P1, P addition with 5 kg P ha$^{-1}$ yr$^{-1}$; P2, P addition with 10 kg P ha$^{-1}$ yr$^{-1}$; P1W, P1 + warming (0.6 °C); P2W, P2 + warming. BDG, β-D-glucosidase activity; NAG, N-acetyl-β-glucosaminidase activity; PHO, phosphatase activity; POX, phenol oxidase activity. Different lower-case letters represent significant differences between treatments. $p < 0.05$. Different colors are used to distinguish different treatments and making it more intuitive.](image)
3.5. PCA and Correlation

PCA (Figure 5) showed that the cumulative percentage of variance in PC1 and PC2 reached 65.41%. The control, P addition alone (P1 and P2), and P addition under warming treatments (P1W and P2W) showed a clear cluster, indicating that P addition and warming significantly affected N$_2$O fluxes and biotic/abiotic factors in Hani peatland. DOC was correlated with vascular plant cover, and BDG, NAG, POX, TN and TP had a high correlation (Figure 5, Table S1).

![Figure 5. Principal component analysis. DOC, dissolved organic carbon; TP, total phosphorus; TN, total nitrogen; WTD, water table depth; VPC, vascular plant cover; SC, Sphagnum cover; BDG, β-D-glucosidase; NAG, N-acetyl-β-glucosaminidase, PHO, phosphatase, POX, phenol oxidase.]

4. Discussion

4.1. Phosphorus Addition and Source/Sink Function of N$_2$O

Hani peatland is a P limited ecosystem [37]. Although P addition alone (P1 and P2) did not significantly affect the N$_2$O flux (Table 1), the response of both N$_2$O flux characteristics and biotic and abiotic factors to the two levels of P addition were different. In CK plots, PHO activity was high (Figure 4c), and it showed a negative correlation with TP, likely indicating a need to increase P availability in the P-limited peatland [7]. Since P is an essential nutrient for microbial growth and metabolism, the lack of P will restrict microbial and extracellular enzyme activities, leading to weak denitrification [46–48]. This should be one of the mechanisms used to explain why N$_2$O fluxes were low in CK plots. Although P1 treatment was not a significant source of N$_2$O during the growing season, a significant N$_2$O emission in August was observed (Figure S2, $p = 0.05$), indicating that long-term P addition alleviated the P restriction of denitrification, resulting in increased N$_2$O fluxes [20,21,49], which proved our first hypothesis, to a certain extent.

Phosphorus addition significantly affected the activities of BDG and NAG ($p < 0.05$, both of two), and the activity of these two enzymes was positively correlated with TP and DOC concentration (Table S1), indicating that P addition promoted the decomposition of peat, which was consistent with our first hypothesis. The DOC concentration, along with BDG and NAG activities, were higher in P1 and P2 treatment plots than in CK, implying that more hydrolases are needed for microorganisms to decompose organic matter to meet their requirement for C and N [50]. This process will finally provide substrates and energy sources to the biochemical processes of N$_2$O production and emissions [51]. Previous studies have shown that the P addition increases the microbial communities in soil [52,53].
thereby accelerating C mineralization, which provides energy sources for nitrification and denitrification [54] that enhance N₂O emissions.

Phosphorus addition with a high dose (P2 treatment) tended to result in N₂O absorption, which may be due to the reduction of N₂O to N₂. Dissolved organic C (DOC) concentration in P2 plots was the highest among all treatments, which may indicate that the available C and N in P2 plots were higher than those in P1 plots. As mentioned above, higher nutrient availability and lower C:N [55,56] were more conducive to the reduction of N₂O to N₂ [57–61]. As an electron donor in denitrification, the concentration of DOC is critical for the occurrence of denitrification, and a higher DOC concentration can stimulate denitrification to consume N₂O, leading to N₂O absorption [62]. Anderson et al. [63] found that the high-level addition of P (250 kg P ha⁻¹) will greatly promote the mineralization of N in grassland ecosystems, thereby stimulating the occurrence of denitrification. O’Neill et al. [64] observed that the cumulative N₂O emissions in “low P soil” (with a P addition level of 30 kg P ha⁻¹ yr⁻¹) were significantly higher than in “high P soil” (45 kg P ha⁻¹ yr⁻¹), because the response of microorganisms to P addition was dose-dependent. In addition, as we mentioned above, a high level of P addition could also lead to the desorption and transfer of available C from the surface soil, which also promotes denitrification.

4.2. Source/Sink Function of N₂O under P Addition Combined with Warming

In our previous study, we found that warming significantly promoted N₂O emissions in Hani peatland [30]. In the current study, the interaction between warming and P addition greatly enhanced both the mean and cumulative N₂O fluxes, which was consistent with our second hypothesis. The TN concentration of P1W and P2W was slightly higher than that under P addition alone. Although it is not statistically significant, slightly more TN can alleviate the N limitation due to the strengthening of decomposition by warming. SEM shows that the addition of P causes an improvement in the activities of BDG and NAG, as well as an increase in DOC and TN concentration, ultimately resulting in an increase in N₂O fluxes. The activities of BDG and NAG are simultaneously affected by warming (Figure S3), and the dual effect of warming and P addition on enzyme activities leads to further enhancement of hydrolase activities and more intense decomposition of organic matter. The close relation between TN concentration and N₂O fluxes shown in PCA further supports our above view. A study of a boreal peatland found a similar mechanism for warming effect on N₂O fluxes [9], and a laboratory experiment demonstrated that warming could transform organic P into inorganic P, which may increase the availability of P in peat soil [65] and further impact N₂O fluxes.

Compared to CK, POX activity clearly increased after P addition and this was related to the increase in vascular plant cover (Figures 5 and 6). The litter of vascular plants was rich in lignin, which need a high level of POX activity to break down [66]. According to the “enzyme latch” hypothesis, high POX activity may reduce phenolics to promote the activities of hydrolases, leading to increased peat decomposition and hence increased DOC concentration, providing an energy source for nitrification and denitrification [6,7,43]. The SEM demonstrates the process through which P addition affects N₂O fluxes by affecting vegetation succession, enzyme activity response, and then organic matter decomposition. Zeng and Wang [67] found that the effect of P addition on forest plant litter was greater than that on aboveground biomass. We believe that there may be a similar mechanism in peatlands, where the input of plant litter was an important factor affecting N₂O production.
Figure 6. Structural equation model between P addition and parameters (Chi-square = 0.494, CFI = 0.990, TLI = 0.984, AIC = 999.11, BIC = 965.01, RMSEA = 0.049, SRMR = 0.007). The red arrow represents positive correlation and the blue arrow represents negative correlation; the numbers on the arrows represent the standardized parameter estimates. DOC, dissolved organic carbon; VPC, vascular plant cover; BDG, β-D-glucosidase activity; NAG, N-acetyl-β-glucosaminidase activity; POX, phenol oxidase activity; TN, total nitrogen.

5. Conclusions

We observed that long-term P addition altered the plant composition of peatland, stimulated enzyme activities, and promoted peat decomposition, resulting in a potential source of N\textsubscript{2}O emissions in the peatland. Warming amplified the effect of P addition to increase N\textsubscript{2}O emissions by stimulating enzyme activities and changing soil stoichiometry, and even turned the peatland into a significant source of N\textsubscript{2}O with an emission of approximate 100 g N\textsubscript{2}O m\textsuperscript{-2} during a growing season. Our results suggest that current and future warming and P deposition caused by global change will greatly promote peatland N\textsubscript{2}O emissions and seriously threaten the N pool function in peatlands.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13122947/s1, Figure S1. Warming effect of open top chambers (OTC) in Hani peatland in the growing season of 2019; Figure S2. Monthly mean N\textsubscript{2}O fluxes (mean ± SE, n = 4) in Hani peatland in the growing season of 2019; Figure S3. Soil enzyme activities under warming (mean ± SE, n = 4). (a) BDG; (b) NAG; (c) PHO; (d) POX; Table S1. Correlation analysis between biological and abiotic factors under P addition and co-effect of P addition and warming in Hani peatland.

Author Contributions: Conceptualization, A.C. and Z.-J.B.; Methodology, Z.-J.B. and B.Y.; Software, B.Y. and F.L.; Validation, A.C.; Investigation, B.Y., F.L. and X.C.; Resources, Z.-J.B.; Data curation, B.Y., J.Z. and J.-X.M.; Writing—original draft, B.Y.; Writing—review and editing, A.C. and Z.-J.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Please contact the author of this article for data.

Conflicts of Interest: The authors declare no conflict of interest.
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