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Nitrogen addition turns a temperate peatland from a near-zero source into a strong sink of nitrous oxide

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Abstract: Peatlands, as important global nitrogen (N) pools, are potential sources of nitrous oxide (N_2O) emissions. We measured N_2O flux dynamics in Hani peatland in a growing season with simulating warming and N addition for 12 years in the Changbai Mountains, Northeastern China, by using static chamber-gas chromatography. We hypothesised that warming and N addition would accelerate N_2O emissions from the peatland. In a growing season, the peatland under natural conditions showed near-zero N_2O fluxes and warming increased N_2O emissions but N addition greatly increased N_2O absorption compared with control. There was no interaction between warming and N addition on N_2O fluxes. Pearson correlation analysis showed that water table depth was one of the main environmental factors affecting N_2O fluxes and a positive relationship between them was observed. Our study suggests that the N_2O source function in natural temperate peatlands maybe not be so significant as we expected before; warming can increase N_2O emissions, but a high dose of N input may turn temperate peatlands to be strong sinks of N_2O, and global change including warming and nitrogen deposition can alter N_2O fluxes *via* its indirect effect on hydrology and vegetation in peatlands.

Keywords: climate change; greenhouse gas; denitrification; terrestrial ecosystem; *Sphagnum*

Peatlands cover only 3% of the global land area (Gorham 1991), but sequestrate approximate 16% of the global nitrogen storage (Limpens et al. 2006), and hence play an important role in the terrestrial ecosystem nitrogen budget. As an important greenhouse gas and the major ozone-depleting compound in the atmosphere, nitrous oxide (N_2O) holds a warming potential about 298 times higher than carbon dioxide (CO_2) at a 100-year scale (Ravishankara et al. 2009). The concentration of N_2O in the atmosphere has increased by more than 20% over the past 250 years, from 270 ppb to 331 ppb, and the increase rate has been accelerating in the past 50 years (Hall et al. 2007). Peatlands storing *ca*. 8–15 Gt nitrogen (N), are the potential source of N_2O emission (Regina et al. 1996, Leppelt et al. 2014, Liimatainen et al. 2018, Minkkinen et al. 2020).

Peatlands in the middle and high latitudes of the northern hemisphere are suffering from relatively strong climate change. These effects, in turn, influence the labile N pools of peatlands (Alm et al. 1999). Updegraff et al. (1995) found that the labile

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N pools subjected to warming would greatly affect the N mineralisation rate in peatlands. In peatlands, especially the *Sphagnum*-dominated ombrotrophic ones, decomposition was very slow due to the acidic, cold and anaerobic environment (Clymo and Hayward 1982). Warming may accelerate the decomposition of organic matter in peatlands and turn, provide more organic substrates for the nitrification and denitrification processes by nitrifying and denitrifying microorganisms. These effects, then, promote the production and emission of N_2O (Voigt et al. 2017, Cui et al. 2018).

Anaerobic environment is beneficial to denitrification in peatlands. It is generally believed that denitrification is the main way for producing N_2O in peatlands (Rückauf et al. 2004). However, the NO_3^- supply was generally low in peatlands, especially bogs and poor fens where the NO_3^- can be limited (Wassen et al. 1995). Along with atmospheric nitrogen deposition, N input from near farmlands (Vitousek et al. 1997, Frolking et al. 2011) would greatly increase the substrate of denitrification and intensify the N_2O production and N_2O emissions. However, there was uncertainty in N_2O emission response to high levels of N addition in peatlands. For example, 1 year of 40 kg N/ha/a addition had no effect on N_2O emissions in two Swedish bogs (Lund et al. 2009), and 100 kg N/ha/a addition for 6 years did not increase N_2O emissions in a Finnish pine bog (Nykänen et al. 2002). A study in tropical artificial peatlands showed that N_2O fluxes under 130 kg N/ha/a addition were significantly higher than other levels of N addition (with a mean below 100 kg N/ha/a) (Chaddy et al. 2019).

The current global change is altering peatland vegetation composition, which has a great impact on N_2O emissions (Bubier et al. 2007, Gong et al. 2020). In the nutrient-limited peatland ecosystem, increased nutrient availability may promote the growth of vascular plants, whereas inhibiting *Sphagnum* (Bubier et al. 2007, Larmola et al. 2013). *Sphagnum* was one of the main users of N in peatlands, and it was also a filter for atmospheric N deposition (Lamers et al. 2000). Nitrogen deposition may negatively affect the N absorption efficiency of *Sphagnum* (Aerts et al. 1992). Vitt et al. (2003) found that the N absorption of *Sphagnum* was greatly reduced when N deposition was greater than 100 kg N/ha/a, resulting in more N entering into the soil, stimulated the nitrification and denitrification process to produce more N_2O, and even promoted the growth of nitrophilic plants like dwarf shrubs (Woodin and Lee 1987, Bragazza et al. 2004, Wieder et al. 2020). Nitrogen addition may increase the content of easily degradable components in *Sphagnum* and vascular plants, and accelerate the decomposition of organic matter (Rudolph and Voigt 2010), which can increase the available substrates to promote the production and emission of N_2O in peatlands.

Besides warming, N addition, vegetation succession, and other environmental changes may also affect N_2O emissions from peatlands (Amha and Bohne 2011, Maljanen et al. 2014). The water table is a key factor affecting oxygen availability along with the peat depth and then nitrification and denitrification in peatlands (Eickenscheidt et al. 2014). Previous studies have shown that water table drawdown will affect the N mineralisation rate, leading to a substantial increase in N_2O emissions (Regina et al. 2010). The increase in pH and soil water content increased the denitrification of peats greatly, no matter ombrotrophic or minerotrophic (Amha and Bohne 2011). The freeze-thaw cycle (Teepe et al. 2001, Yu et al. 2010), soil oxidation-reduction potential, peatland type and the available C concentration also affect N_2O fluxes (Frasier et al. 2010, Buchen et al. 2019, Hatano 2019, Minkkinen et al. 2020).

So far, the global change and the interaction between high N levels and warming on N_2O emissions from peatlands in the mid-temperate zone have been rarely studied. We used static chamber-gas chromatography to measure the N_2O emission characteristics of a peatland in the Changbai Mountains during the 2019 growing season. We hypothesised: (1) the control plots would clearly show N_2O emissions since natural peatlands usually are the N_2O source during growing seasons; (2) warming would increase N_2O emissions due to increased N availability by facilitating decomposition; (3) N addition would promote N_2O emissions because it increases the substrate of nitrification and denitrification, and (4) warming + N addition would greatly increase N_2O emissions and hence strengthen N_2O source function of the ecosystem.

MATERIAL AND METHODS

Study site. The study site, Hani peatland (126°31'05''E, 42°12'50''N), is located in the west foot of the Changbai Mountains in Northeast China, with an altitude of 900 m a.s.l. It is a large peatland with an area of *ca*. 16.8 km^2 and a peat depth of *ca*. 3–10 m

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(Zhang et al. 2019). The peatland is a transitional mire from eutrophic to oligotrophic. The temperature is low throughout the year, with an average annual temperature of 2.5–3.6 °C, and an annual active accumulated temperature of ≥ 10 °C is about 2 600 °C. The annual precipitation is 757–930 mm. The tree *Larix gmelinii* var. *olgensis* (A. Henry) Ostenf. & Syrach, the dwarf shrub *Betula ovalifolia* Rupr., the graminoids *Carex lasiocarpa* Ehrh., *Eriophorum polystachion* L. and *Phragmites australis* (Clav.) Trin., and the bryophytes *Sphagnum magellanicum* Brid., *S. fuscum* (Schimp.) Klinggr., *S. imbricatum* Hornsch. ex Russow and *S. subsecundum* Nees. are common in the peatland (Bu et al. 2011).

Experimental design. A field experiment was conducted in the long-term global change simulation plots (initiated from 2007) in Hani peatland (Bu et al. 2011). Of the 72 plots (0.8 m × 0.8 m), 16 plots, including 4 treatments (control (CK), N addition (N), warming (W), and warming + N addition (WN)), each with 4 replicates, were chosen for the experiment. Warming was achieved through passive temperature increase with open-top chambers (OTC). In May 2018, OTCs (1.2 m × 1.2 m at the bottom and 0.8 m × 0.8 m at the top) were placed to surround the plots. Nitrogen addition was achieved by applying NH_4NO_3 solution with a dose of 100 kg N/ha/a which is 4 times of average nitrogen deposition level in the area of the Changbai Mountains (Zhou et al. 2015). Three hundred mL of NH_4NO_3 solution with an N concentration of 4.26 g/L was prepared and sprayed in each plot monthly during the growing season (from May to September). The same amount of pure water was added in the plots without N addition. Boardwalk was paved in the previous autumn to reduce the possible disturbance to gas sampling.

Gas sampling and analysis. The static chamber-gas chromatography method was used to measure N_2O fluxes. In each sampling plot, a PVC soil respiration collar (25 cm in diameter, 14 cm in height) with a groove for chamber placement was fitted in the soil at 5 cm depth in October 2018, to allow recovery of any damaged roots and disturbance caused by collar installation. From May to September in 2019, gas samples were collected twice in May, July and September and once in June and August. During gas sampling, an opaque acrylic plexiglass static chamber with a diameter of 25 cm and a height of 50 cm was placed on the collar. The collar was supplied with water sealing at the top groove to ensure an airtight connection with the chamber, and the top of the chamber is equipped with a gas extraction tube and a balanced air pressure tube, as well as a mini fan for evening the air and reducing the temperature in the chamber. Gas samples were taken from the chamber headspace and then stored using 60 mL gas syringes at 0, 10, 20 and 30 min, respectively, after closure. After each sampling, the static chamber was lifted from the soil respiration collar to restore the temperature and N_2O concentration in the chamber to the surrounding environment. The sampling time was from 9:00 a.m. to 2:00 p.m. Gas chromatograph (Agilent 7980B, Santa Clara, USA) was employed to analyse the gas in the Biogeochemistry Laboratory of School of Geographical Science, Northeast Normal University within two weeks after sampling. Nitrous oxide concentration was detected by an electron capture detector. The concentration of the 4 gas samples collected within 30 min was linearly related to the sampling interval, and the slope of the linear equation was used to calculate the N_2O flux of the sample. Fluxes were accepted when the determination coefficient between fluxes and sampling time intervals was greater than 0.75.

Measurement of environmental factors and estimation of vegetation cover. Meteorological data including rainfall, temperature, humidity, air pressure, and photosynthetic radiation was obtained from the weather station in the study site. A button thermometer (Lascar Electronics Ltd., Whiteparish, UK) was kept 10 cm above the moss surface by being tied to a brush and inserted into the soil to monitor the air temperature of the four typical treatment samples continuously and automatically throughout the whole growing season. The soil temperature of 5 cm and 20 cm underground was measured around the collar with a soil thermometer while measuring the N_2O emission. Water table depth (WTD, distance from moss surface to water table) was measured by inserting a PVC observation well next to each sample square. Peat water pH was measured by a multi-parameter analyser (HQ30D, Shanghai Reunion Science Instrument Co. Ltd, Shanghai, China). Soil temperature, pH and WTD were measured twice a month. At the end of July 2019, plant cover in each soil respiration collar of each plot was estimated by the visual inspection method (Liu et al. 2015).

Peat water/soil sampling and analysis. In early August 2019, peat porewater 10 cm below the moss surface in the PVC well and soil 5–10 cm below the moss surface in the soil respiration collar were col-

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lected from each plot. In the laboratory, peat water was filtered by an oil-free diaphragm vacuum pump with 0.45 μm microfiltration membrane and then measured dissolved organic carbon (DOC) concentration with a TOC analyser (Aurora 1030, OI Analytical, College Station, USA). Peat soil samples were dried at 60 °C to a constant weight, then put into a ball mill (GT200, Grinder, Beijing, China) for grinding and homogenising. After being weighted, the samples were then employed TC and TN analysis with an element analyser (Euro Vector 3000, Pavia, Italy).

Data analysis. Repeated measures analysis of variance (ANOVA) was used to analyse the effects of warming, N addition, and their interaction on N_2O emissions. Normality test of the data was analysed before, and the data of TN and TC were logarithmic transformation. Two-way ANOVA was used to analyse the effects of different treatments on vegetation cover, TC, TN, DOC, soil temperature (5 cm and 20 cm), WTD and other non-biological environmental factors. Pearson correlation analysis was used to analyse the correlation between N_2O fluxes and environmental factors. Statistical analysis was performed in R 3.5.3 (Development Core Team, 2019) and SPSS 19 statistical software package (SPSS, Inc., Chicago, USA).

RESULTS

Environmental factors. During the growing season, the warming treatment significantly increased the average air temperature by 0.51 °C (Figure 1). The differences in environmental factors among treatments are shown in Table 1. Although there was no significant difference in the soil temperature at 5 cm and 20 cm depth among the four treatments, they were lower in warming treatment than control by 1.1 °C and 0.5 °C, respectively. WTD in N addition and WN plots was lower than control. From May to July 2019, WTD of all the four treatments gradually decreased over time (Figure 2), being lowest in August, but tended to increase in September, nearly the same as that in early May. DOC concentration of control was lower than the other three treatments, among which no significant difference in DOC was observed. TN concentration of the two treatments with N addition was higher than that without N addition treatments. TC concentration of the WN treatment was higher than that without N addition treatments. The C/N ratio among the four treatments was different, the C/N ratio in control plots was higher than in the other three treatments, and in N addition plots were higher than without N addition treatment plots. No significant difference in pH among the four treatments was found.

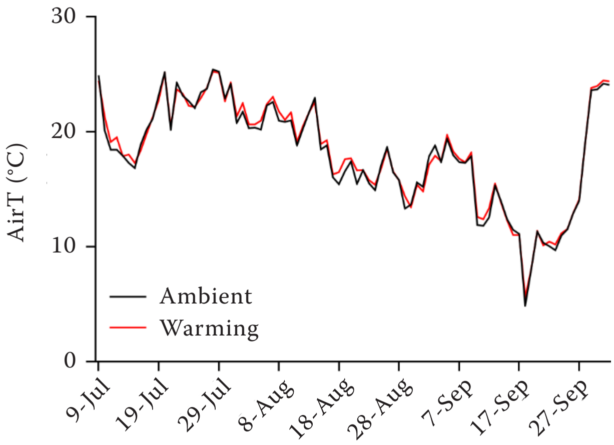

Figure 1. Daily mean air temperature in the warming plots (red line) and control plots (black line) in the growing season of 2019

N_2O fluxes. Repeated measurement ANOVA showed that both warming and N addition had

Table1. Environmental parameters of peat soil in different treatments during the growing season of 2019 (mean ± standard error of the mean)

Treatment	T_{soil}, 5 cm (°C)	T_{soil}, 20 cm (°C)	WTD (cm)	DOC (μg/mL)	pH	TN (%)	TC (%)	C/N
CK	18.25 ± 0.5^a	11.82 ± 1.0^a	29.94 ± 3.8^c	4.29 ± 0.7^a	6.19 ± 0.1^a	1.11 ± 0.1^a	37.79 ± 0.3^b	34.04 ± 0.9^c
W	17.32 ± 0.9^a	11.36 ± 0.8^a	23.91 ± 3.0^{bc}	6.68 ± 0.6^b	5.97 ± 0.1^a	1.32 ± 0.1^b	34.13 ± 2.1^b	26.03 ± 2.1^b
N	16.53 ± 1.2^a	10.67 ± 0.5^a	15.65 ± 1.8^a	7.29 ± 0.8^b	6.00 ± 0.2^a	1.50 ± 0.1^{bc}	32.96 ± 1.8^{ab}	22.15 ± 1.8^a
WN	15.35 ± 1.4^a	10.07 ± 0.4^a	13.58 ± 1.1^a	6.69 ± 0.6^b	6.05 ± 0.2^a	1.71 ± 0.1^c	33.93 ± 1.1^a	20.06 ± 1.4^a

CK – control; W – warming; N – N addition; WN – warming + N addition; WTD – water table depth; DOC – dissolved organic carbon; TN – total nitrogen; TC – total carbon. Different lowercase letters represent significant differences ($P < 0.05$) between the treatments

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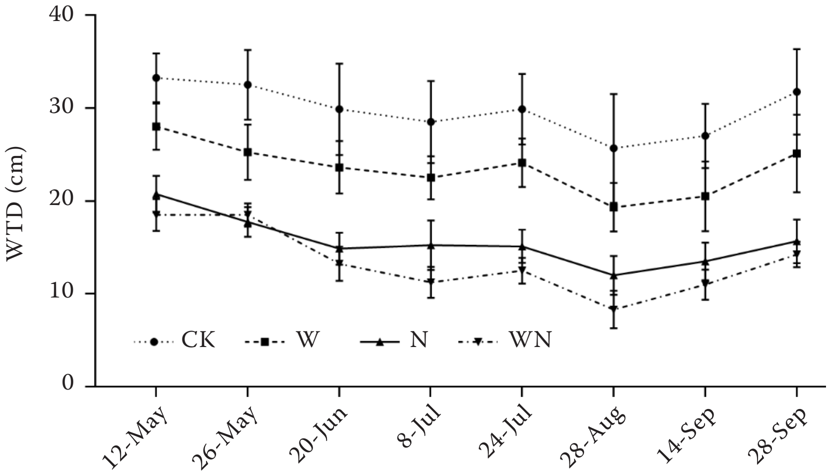

Figure 2. Temporal variation of water table depth (WTD) in Hani peatland in the growing season of 2019 (mean ± standard error of the mean, n = 4). CK – control; W – warming; N – N addition; WN – warming + N addition

a significant effect on N_2O fluxes, but no interaction between the two factors was observed (Table 2). Under natural conditions (control), a N_2O flux –37.8 ± 61.6 g/m^2/a was monitored but it was not significantly different from zero (Figure 3, P = 0.562). Nitrogen addition enhanced N_2O absorption and warming enhanced N_2O emissions. However, N_2O fluxes in the combined treatment of warming and N addition had no difference from that in the control treatment, and it was also in a state of absorption. Compared with the control treatment, N addition increased N_2O absorption by 126.45 g/m^2/a, while warming increased N_2O emissions by 92.07 g/m^2/a.

Temporal variation of N_2O fluxes. The temporal variation of N_2O fluxes was consistent with the water table depth. During the growing season (May to July), all the treatments showed similar N_2O flux dynamics with a relatively steady zero flux from early May to early August, a strong absorption peak in late August, and a clear emission peak in late September. The first peak may be related to emission obstacle due to rich rainfall and high water table in late August; while the second peak may be subject to the delayed emission obstacle release due to sudden decrease of the water table (Figures 2 and 4). This inference can be supported experimentally by Martikainen et al. (1993) and Kachenchart et al. (2012), both of whom found increased N_2O emissions when water table depth increased.

Vegetation cover change and the relationship between N_2O fluxes and environmental factors. Both N addition and warming + N addition decreased *Sphagnum* cover compared with control (P < 0.05 for both), and there was no significant effect of experimental treatment on vascular plant cover (Figure 5).

Pearson correlation analysis showed that soil temperatures at 5 cm and 20 cm, WTD, DOC in peat porewater and TN and TC in peat soil had no relation with N_2O fluxes, while WTD showed a positive relation with N_2O fluxes (Table 3, Figure 6).

Table 2. Repeated measures ANOVA of N_2O fluxes under different treatments

Treatment	*df*	*F*	*P*
Warming	1	4.503	0.036*
N addition (N)	1	4.225	0.042*
N × warming	1	0.334	0.853

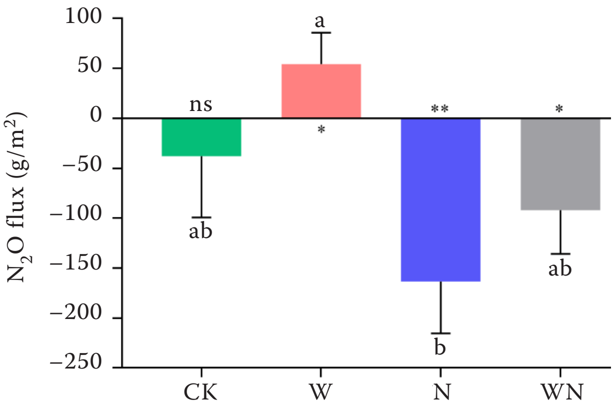

Figure 3. Cumulative N_2O fluxes (mean ± standard error of the mean, n = 4) in Hani peatland in the growing season of 2019 (153 days in total). CK – control; W – warming; N – N addition; WN – warming + N addition. Different lowercase letters represent significant differences (P < 0.05). Asterisks denote N_2O flux significantly different from zero. *P < 0.05; **P < 0.01; ns – no significant difference

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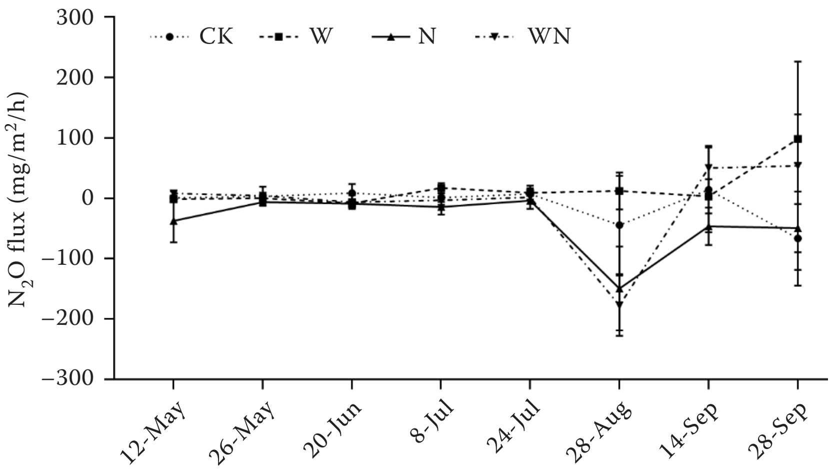

Figure 4. Temporal variation of N_2O fluxes in Hani peatland in 2019 (mean ± standard error of the mean, n = 4). CK – control; W – warming; N – N addition; WN – warming + N addition

DISCUSSION

Source and sink function of N_2O in the natural peatland. It is well believed that natural peatlands are an important potential source of N_2O emissions (Dinsmore et al. 2009, Maljanen et al. 2010, Burgin and Groffman 2012, Cui et al. 2018). However, in contrast to our first hypothesis, our experiment found that Hani peatland in the growing season was not a source of but even tended to be a sink of N_2O. Recent studies in a boreal peatland of Canada, similarly, reported a net-zero N_2O flux during the growing season although yearly variation was observed (Gong et al. 2018, 2019). In seasonal dynamics, the peatland even performed as a clear N_2O sink in July 2015 and August 2016, rather similar to our observations in late August and late September 2019. The contrasted result for N_2O fluxes is probably related eco-hydrological type of the peatland (Li et al. 2019, Chen et al. 2020). As a transitional mire, long-lasting high water table and anaerobic environment of Hani peatland are not in favour of N_2O emission under natural state since the intermediate product N_2O of denitrification would be reduced to N_2 and emitted into the atmosphere. This might be the reason why a waterlogging peatland was a sink of N_2O (Bowden 1986, Rückauf et al. 2004). Liimatainen et al. (2014) found that denitrification was the main reaction to produce N_2O under anaerobic conditions, but more N_2O was produced after acetylene was used to inhibit the reduction of N_2O to N_2, which indirectly indicated that more N_2O was reduced to N_2 in peatlands with poor aeration conditions.

Source and sink function of N_2O and warming. Inconsistent with the second hypothesis, warming plots were detected to perform as a source of N_2O fluxes. The cover of vascular plants in warming treatment was the highest among all the treatments, indicating that warming promoted the growth of

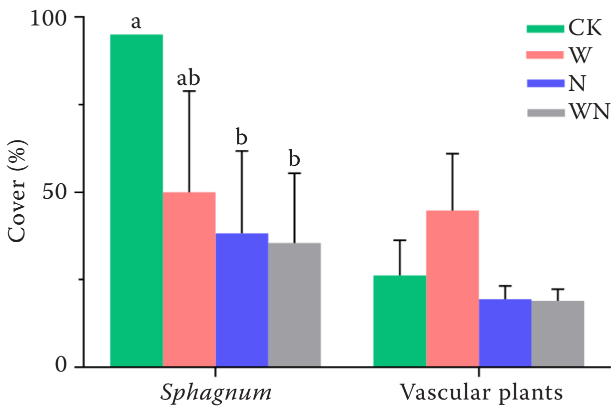

Figure 5. Vegetation cover in the plots in different treatments (mean ± standard error of the mean, n = 4). CK – control; W – warming; N – N addition; WN – warming + N addition. Different lowercase letters represent significant differences (P < 0.05)

Table 3. Pearson correlation between N_2O fluxes and environmental parameters

Environmental parameter	*r*	*P*
T_{soil} 5 cm	0.216	0.421
T_{soil} 20 cm	0.121	0.654
WTD	0.538	0.042*
DOC	0.034	0.901
pH	0.082	0.762
TC	0.281	0.292
TN	–0.152	0.575

T – temparature; WTD – water table depth; DOC – dissolved organic carbon; TC – total carbon; TN – total nitrogen

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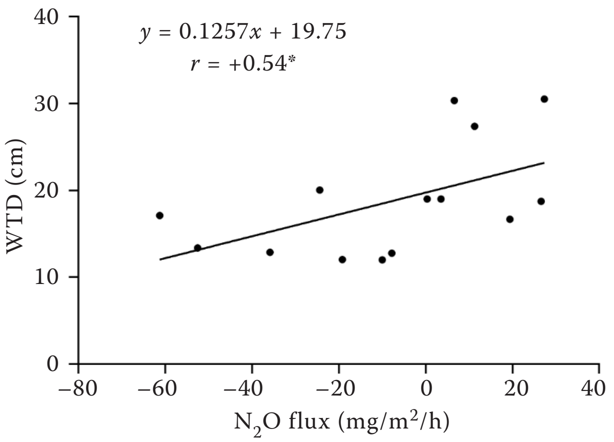

Figure 6. Correlation between N_2O fluxes and water table depth (WTD)

vascular plants. Given no significant difference in water table depth between warming and control plots (Table 1), the increase of N_2O emissions relative to control plots may be attributed to the cover increase of vascular plants. The aerenchyma of vascular plants could promote N_2O emissions by providing pathways for N_2O produced in deep peat to escape to the atmosphere in the warming treatment (Le et al. 2021). Low C/N ratio and high DOC in warming plots due to accelerated decomposition of organic matter may provide more energy sources for denitrifying microorganisms to increase N_2O production and fluxes (Hu et al. 2016). It is well known that the most suitable temperature for denitrification was 30–65 °C (Malhi et al. 1990). In our study, the soil temperature of all four treatments was relatively low in the whole growing season. This may explain why the peatland in natural or even warming conditions showed low N_2O emissions.

Source and sink function of N_2O and N addition. In contrast to the third hypothesis, N addition did not increase N_2O emissions but enhanced absorption, which was rarely observed in previous studies (Couwenberg et al. 2010, Oktarita et al. 2017). Similar to our study, Leeson et al. (2017) found that 13 years of N input in the level of 64 kg/ha/a which was lower than the level in our study could reduce N_2O emissions, and they inferred that vegetation composition might be related to the N_2O flux. We recognise that the N addition level in our study is rather higher than most of the previous studies (e.g. Lund et al. 2009, Leeson et al. 2017, Gong et al. 2018). The unusual N_2O absorption may be related to surface subsidence because of continuous high-level of N addition killing *Sphagnum* mosses (Figure 6) and increase surficial peat decomposition (Bubier et al. 2007, Moore et al. 2019), which could be indicated by decreased C/N ratio in peat and elevated DOC in porewater. This result could be explained as that soil moisture increased with water table depth decrease, and the N_2O produced by denitrification was further reduced to N_2, which eventually led to a decrease in N_2O fluxes. Another possibility is that our N availability in the long-term N addition plots with TN 35% greater than control was so high that it inhibited denitrification microbes to produce N_2O (Tedeschi et al. 2021). In further studies, NO_3^- concentration measurement may answer whether NO_3^- is rich enough to inhibit denitrification like in mineral soils (Sosulski et al. 2020).

Source and sink function of N_2O after N addition and warming. In the study, we found no interaction between warming and N addition. And contrary to the fourth hypothesis, warming + N addition did not greatly increase N_2O emissions. The N_2O fluxes in warming + N addition treatment were negative during the whole growing season.

However, the absorption intensity was lower than that in N addition plots, probably due to the effect of warming on N_2O emissions partly offsetting the N_2O absorption effect caused by N addition. In a similar N addition and warming experiment, Gong and Wu (2021) found no significant emissions under warming (1.2–2.6 °C) + N treatment (64 kg N/ha/a). They believed that warming promoted the growth of vascular plants which would compete with denitrifiers for nitrogen to reduce the positive effect of N addition on N_2O emissions. This mechanism may also work in our experiment since compared with N treatment, warming + N treatment indeed decreased N_2O emissions. In seasonal emission dynamics, slightly stronger N_2O emissions in warming + N addition treatment was detected in September which should be mainly attributed to the warming effect.

Vegetation and N_2O fluxes. There were obvious differences in vegetation cover among the four treatments, especially in N addition treatment compared with control. As mentioned above, the effect of each treatment on N_2O fluxes might be indirectly caused by the change of vegetation composition and other environmental factors, such as WTD. Long-term N addition and warming treatment, resulting in significant changes in vegetation composition among treatments, and the impact of this change on N_2O fluxes has exceeded the direct impact of our treat-

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ment on N_2O fluxes. In other words, the long-term cumulative effect caused by global change is greater than the short-term instantaneous effect (Cheng et al. 2016, Moore et al. 2019).

In summary, the study monitored N_2O emission characteristics of Hani peatland under simulated environmental changes including warming and N addition. We found a near-zero N_2O emission in the peatland during the whole growing season, and the peatland became a strong N_2O sink when there is a continuous 100 kg N/ha/a input for 12 years. Warming of about 0.5 °C in the growing season promoted N_2O emissions, resulting in net N_2O emissions while the emissions were weakened by N addition, leading to a near-zero N_2O flux. N_2O fluxes in all the treatments showed similar seasonal dynamics, with near-zero emissions from May to July, and an absorption peak in late August, which accounted for approximately 45% of the whole growing season flux, and then minor emissions in September. Pearson correlation analysis showed that the water table was the key environmental factor leading to seasonal variation in N_2O emissions. Furthermore, a high level of N addition exacerbated the death of *Sphagnum*, while warming promoted the growth of vascular plants. Our study suggests that a long-term global change, especially N deposition, may strongly affect N_2O fluxes in temperate peatlands, and even change the source or sink function of peatlands, which may be achieved indirectly *via* affecting hydrology or vegetation.

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