Management scheme influence and nitrogen addition effects on soil CO$_2$, CH$_4$, and N$_2$O fluxes in a Moso bamboo plantation

Junbo Zhang$^{1\dagger}$, Quan Li$^{1\dagger}$, Jianhua Lv$^1$, Changhui Peng$^2$, Zhikang Gu$^3$, Lianghua Qi$^4$, Xuzhong Song$^5$ and Xinzhang Song$^1\ast$

Abstract

Background: It is still not clear whether the effects of N deposition on soil greenhouse gas (GHG) emissions are influenced by plantation management schemes. A field experiment was conducted to investigate the effects of conventional management (CM) versus intensive management (IM), in combination with simulated N deposition levels of control (ambient N deposition), 30 kg N ha$^{-1}$ year$^{-1}$ (N30, ambient + 30 kg N ha$^{-1}$ year$^{-1}$), 60 kg N ha$^{-1}$ year$^{-1}$ (N60, ambient + 60 kg N ha$^{-1}$ year$^{-1}$), or 90 kg N ha$^{-1}$ year$^{-1}$ (N90, ambient + 90 kg N ha$^{-1}$ year$^{-1}$) on soil CO$_2$, CH$_4$ and N$_2$O fluxes. For this, 24 plots were set up in a Moso bamboo (Phyllostachys edulis) plantation from January 2013 to December 2015. Gas samples were collected monthly from January 2015 to December 2015.

Results: Compared with CM, IM significantly increased soil CO$_2$ emissions and their temperature sensitivity ($Q_{10}$) but had no significant effects on soil CH$_4$ uptake or N$_2$O emissions. In the CM plots, N30 and N60 significantly increased soil CO$_2$ emissions, while N60 and N90 significantly increased soil N$_2$O emissions. In the IM plots, N30 and N60 significantly increased soil CO$_2$ and N$_2$O emissions, while N60 and N90 significantly decreased soil CH$_4$ uptake. Overall, in both CM and IM plots, N30 and N60 significantly increased global warming potentials, whereas N90 did not significantly affect global warming potential. However, N addition significantly decreased the $Q_{10}$ value of soil CO$_2$ emissions under IM but not under CM. Soil microbial biomass carbon was significantly and positively correlated with soil CO$_2$ and N$_2$O emissions but significantly and negatively correlated with soil CH$_4$ uptake.

Conclusion: Our results indicate that management scheme effects should be considered when assessing the effect of atmospheric N deposition on GHG emissions in bamboo plantations.

Keywords: Greenhouse gases, Management practices, Nitrogen addition, Phyllostachys edulis, $Q_{10}$
Introduction

Extensive research on soil greenhouse gases (GHGs) has shown that CO$_2$, CH$_4$, and N$_2$O released from soil significantly contribute to global warming (IPCC 2013; WMO 2019). Atmospheric concentrations of CO$_2$, CH$_4$, and N$_2$O have increased considerably from 278 ppm, 722 ppb, and 270 ppb in 1750 to 408 ppm, 1869 ppb, and 331 ppb in 2018, respectively (WMO 2019). Forest ecosystems, as an important source of atmospheric CO$_2$ and N$_2$O and an important sink of CH$_4$ (Liu and Greaver 2009), play a key role in regulating GHG fluxes under global climate change.

Recently, atmospheric N deposition has drastically increased in East and South Asia and is expected to continue to increase (Galloway et al. 2008; Reay et al. 2008; Tian et al. 2016), particularly in subtropical China (Liu et al. 2013), where N deposition has reached 30.9 kg N·ha$^{-1}·$year$^{-1}$ (Xie et al. 2008) and is predicted to reach 50 kg N·ha$^{-1}·$year$^{-1}$ by 2050 (Galloway et al. 2004). Many studies have shown that N deposition can significantly influence forest soil CO$_2$, CH$_4$, and N$_2$O emissions, including both promotion and inhibition effects (Zhang et al. 2008a; Liu and Greaver 2009; Deng et al. 2020). For example, in temperate forests, the effect of N deposition on soil CO$_2$ emissions includes promotion (Bowden et al. 2004; Zheng et al. 2018) and inhibition (Geng et al. 2017), as well as no effect (Krause et al. 2013; Sun et al. 2014). N deposition reduces (Sitaula et al. 1995; Guldledge et al. 2004; Kim et al. 2012; Krause et al. 2013) or increases (Geng et al. 2017) soil CH$_4$ uptake and accelerates soil N$_2$O emissions (Ventera et al. 2003; Kim et al. 2012; Krause et al. 2013; Sun et al. 2014; Song et al. 2017a). In tropical forests, N deposition reduces soil CO$_2$ emissions (Mo et al. 2008; Cusack et al. 2011; Tian et al. 2019) and enhances (Zhang et al. 2008b; Wang et al. 2014; Tian et al. 2019) or has no effect (Zhang et al. 2008b; Müller et al. 2015; Tang et al. 2018) on soil N$_2$O emissions; and inhibits or has no effect on soil CH$_4$ uptake (Zhang et al. 2012). N deposition was shown to promote soil N$_2$O emissions in an N-saturated forest (Xie et al. 2018), while it increased soil CO$_2$ emissions in a bamboo ecosystem (Tu et al. 2013), an evergreen forest (Gao et al. 2014), and a highly P-limited forest (Liu et al. 2019). Additionally, Wang et al. (2015) found that N deposition promoted soil N$_2$O emissions but reduced soil CH$_4$ uptake in a slash pine plantation. Li et al. (2015) also measured the effects of N deposition in a slash pine plantation and found that soil CO$_2$ and N$_2$O emissions increased, but soil CH$_4$ uptake was unaffected. These inconsistent results indicate that the effects of N deposition on GHG emissions strongly depend on forest type. Moreover, most studies have only observed the fluxes of one or two GHGs in forest soil under N deposition (Jassal et al. 2010; Kim et al. 2012; Wang et al. 2015; Tian et al. 2019). Studies that simultaneously measure the fluxes of three GHGs in forest soils under increasing N depositions are scarce (Krause et al. 2013; Song et al. 2017a), especially in subtropical plantations (Li et al. 2015; Song et al. 2020).

An increasing number of plantations have been established in recent years to satisfy the increasing global demand for timber products (FAO 2005). As one of the forestry practices that increases productivity, intensive management (IM) is essential for meeting current and future timber needs (McIwan et al. 2020). Several studies have shown that IM significantly increases CO$_2$ emissions (Mori et al. 2017; Yang et al. 2017) but does not affect CH$_4$ or N$_2$O emissions from forest soils (Mori et al. 2017). Moso bamboo (Phyllostachys edulis) plantations are one of the most important types of forests in southern China. Approximately 4.43 million hectares are under Moso bamboo cultivation in this region, comprising 84.02% of the global Moso bamboo forest area (Song et al. 2017b). In recent decades, owing to the high economic and ecological benefits of Moso bamboo, an increasing number of farmers have utilized IM practices to replace conventional management (CM) practices in Moso bamboo plantations, including fertilization, plowing, and weeding understory vegetation (Song et al. 2015). In Moso bamboo plantations, IM has been observed to significantly increase soil CO$_2$ emissions (Liu et al. 2011; Tang et al. 2016), while its effects on soil N$_2$O and CH$_4$ fluxes remain unknown. Therefore, the effect of IM on soil GHG emissions in Moso bamboo plantations is an empirical gap that needs to be addressed.

Furthermore, Moso bamboo plantations are located in subtropical China where N deposition had increased dramatically in recent years (Liu et al. 2013). Our previous study showed that N deposition increased soil CO$_2$ emissions (Li et al. 2019) and N$_2$O emissions (Song et al. 2020) but decreased soil CH$_4$ uptake (Song et al. 2020) in Moso bamboo plantations under IM. However, the comprehensive effects of management scheme combined with N deposition on soil GHG fluxes in Moso bamboo plantations remain unclear. Here, we studied the individual and combined effects of N deposition and management scheme on soil CO$_2$, CH$_4$, and N$_2$O fluxes for one year in a Moso bamboo plantation. We hypothesized that (1) IM increases CO$_2$ emissions but does not affect N$_2$O emissions or CH$_4$ uptake, because IM can promote soil respiration; (2) N addition promotes CO$_2$ and N$_2$O emissions but inhibits CH$_4$ uptake under CM, because N addition can promote soil respiration, nitrification and denitrification but inhibit methane oxidation; and (3) IM intensifies the effect of N addition on soil GHG fluxes, because IM can provide more nutrient, especially N.

Materials and methods

Study site

The details of the study site were reported previously (Song et al. 2015). Briefly, the site is located in Lin’an
District (30°14’ N, 119°42’ E), Hangzhou City, Zhejiang Province, China, and is characterized by a subtropical monsoon climate with a mean annual temperature of 15.6 °C and a mean annual precipitation of 1420 mm. The soil belongs to the Ferrisols derived from granite (Song et al. 2015). The landscape is hilly, with an elevation range of 100 to 300 m a.s.l. The Moso bamboo plantations were initially established in the late 1970s to replace a native evergreen broadleaf forest, with similar soil type and topography (a southwest slope of approximately 6°). Moso bamboo forests in the study area are divided into CM and IM plantations according to the management scheme to which they are subjected. Conventionally managed plantations are selectively and regularly harvested for bamboo stems and shoots according to demand, with no other management practices in place. In IM plantations, additional management practices such as plowing, weeding by herbicide spray, and fertilization are practiced, in addition to bamboo harvesting as per CM plantations. Specifically, every year in September, fertilizers (67.5 kg N·ha−1, 11.8 kg P·ha−1, and 74.7 kg K·ha−1) are evenly spread on the ground and then plowed to mix with the 30-cm topsoil (Song et al. 2015). Compared with CM plantations, IM plantations have fewer understory species and lower shrub and herbal biomass. Forest stand and soil characteristics at the study site are shown in Table 1 (Song et al. 2015).

Table 1 Forest stand and soil characteristics in the Moso bamboo forests at the study site

| Management Scheme | Stand density (trees·ha−1) | DBH (cm) | SBD (g·cm−2) | SOC (mg·g−1) | TN (mg·g−1) | AN (mg·g−1) | TP (mg·g−1) | AP (mg·g−1) | Soil pH |
|-------------------|---------------------------|---------|--------------|-------------|-------------|-------------|-------------|-------------|--------|
| CM                | 3106 ± 386a               | 10.08 ± 0.38a | 1.06 ± 0.07a | 27.8 ± 0.3a | 0.9 ± 0.03b | 0.06 ± 0.00b | 0.4 ± 0.01a | 0.002 ± 0.000a | 4.53 ± 0.02a |
| IM                | 3362 ± 309a               | 10.16 ± 0.13a | 0.97 ± 0.07a | 23.7 ± 0.2b | 1.1 ± 0.04a | 0.09 ± 0.00a | 0.5 ± 0.01a | 0.002 ± 0.000a | 4.46 ± 0.01a |

CM conventional management; IM intensive management; DBH diameter at breast height; SBD soil bulk density; SOC soil organic C; TN soil total N; AN available N; TP soil total P; AP available P. Different small letters within columns indicate significant difference at the 0.05 level.

Experimental design and measurements
In November 2012, 24 plots (20 m × 20 m) with a 20-m-wide buffer zone (to avoid disturbing nearby plots) were set up in the Moso bamboo plantations of the study site. According to the N-deposition simulation method reported by Mo et al. (2007) and background atmospheric N deposition data of the site (30.9 kg N·ha−1·year−1) during 2007–2009, the amount of NH4NO3 (Xilong Chemical Co. Ltd., China) corresponding to each N treatment was dissolved in 10 L of water and uniformly sprayed on the forest floor of each N-treated plot in CM and IM plantations once a month (Song et al. 2015). Each control treatment plot was sprayed with 10 L of N-free water to balance the effects of added water.

Measurement of soil GHG fluxes
Soil CO2, CH4, and N2O were collected using the static chamber method. The static chamber assembly consists of a permanently mounted base box (40 cm × 40 cm × 10 cm) with a U-shaped groove (5 cm wide and 5 cm deep) at the top and a removable cover box (40 cm × 40 cm × 40 cm). During gas sampling, the cover boxes were placed onto the base boxes and the grooves filled with water to serve as an air seal. A small fan was installed in each chamber to mix the air within the chamber during sampling. The base frame was directly inserted 5 cm into the soil in January 2013. Sampling was conducted between 9:00 am and 10:00 am to minimize the influence of variation. Four samples were taken with a 60-mL plastic syringe attached to a 3-way stopcock every 10 min for 30 min (i.e., at 0, 10, 20, and 30 min). Button thermometers (iButton DS1923; Wdsen Electronic Technology Co. Ltd., China) buried at a depth of 5 cm were used to monitor soil temperature at hourly intervals. GHG concentrations were analyzed after Li et al. (2019) using a gas chromatographer (GC-2014 Shimadzu Corp., Japan) within two days. We collected GHG emission data on a clear day once a month from January to December 2015. Gas fluxes were calculated using the following equation (Li et al. 2019):

\[ R = \frac{\Delta c}{\Delta t} \times \rho \times \frac{273}{273 + T} \times \frac{V}{A} \times n \]  

where \( R \) is gas flux (mg CO2-C·m−2·h−1 for CO2, μg CH4-C·m−2·h−1 for CH4, and μg N2O·O-N·m−2·h−1 for N2O), \( \rho \) is gas density under normal conditions (mg·m−3), \( V \) is the volume of the static chamber (m3), \( A \) is the area that the static chamber covered, \( \Delta c/\Delta t \) is the change in gas concentration (Δc) during a certain time (Δt), \( T \) is air temperature (°C), and \( n \) is the coefficient...
for converting the masses of CO$_2$, CH$_4$, and N$_2$O to the masses of C and N (12/44 for CO$_2$, 12/16 for CH$_4$, and 28/44 for N$_2$O).

The following equation was used to calculate cumulative soil CO$_2$, CH$_4$, and N$_2$O fluxes (Liu et al. 2011):

$$ F_g = \frac{R_{i+1} + R_i}{2} \times (t_{i+1} - t_i) \times 24 \times d $$

where $F_g$ is cumulative soil CO$_2$ (kg CO$_2$-C·ha$^{-1}$·year$^{-1}$), CH$_4$ (kg CH$_4$-C·ha$^{-1}$·year$^{-1}$), or N$_2$O (kg N$_2$O-N·ha$^{-1}$·year$^{-1}$) flux; $R$ is soil CO$_2$ (mg CO$_2$·C·m$^{-2}$·h$^{-1}$), CH$_4$ (mg CH$_4$·C·m$^{-2}$·h$^{-1}$), or N$_2$O (mg N$_2$O·N·m$^{-2}$·h$^{-1}$) flux determined at each sampling time; $i$ is the sampling number, $t$ is the sampling time, and $d$ is the number of days in each month.

Based on these measurements, an exponential regression model was used to describe the relationship between soil CO$_2$ efflux and soil temperature (Li et al. 2019):

$$ Y = \alpha \times e^{kT} $$

where $Y$ is soil CO$_2$ efflux, $T$ is soil temperature at 5-cm depth, and $\alpha$ and $k$ are the model coefficients. Soil CO$_2$ efflux temperature sensitivity ($Q_{10}$) was calculated as in Li et al. (2019):

$$ Q_{10} = \alpha \times e^{(T+10)/\alpha} \times e^{10k} $$

The Global warming potential (GWP) metric was developed to allow comparisons of the global warming impacts of different gases. The GWP of soil GHG emissions was computed by considering the respective GWP coefficients of CH$_4$ and N$_2$O using the following equation (Tian et al. 2015):

$$ \text{GWP (t CO$_2$eq·ha$^{-1}$) = } \frac{F_{CO_2} \times 44}{12} + F_{CH_4} \times 25 \times \frac{16}{12} + F_{N_2O} \times 298 \times \frac{44}{28} $$

**Soil analysis**

Ten soil cores (3.5-cm inner diameter) were collected randomly from the topsoil layer (0–20 cm) in each plot in every quarter of 2015. The soil samples were sieved through a 0.15-mm sieve and divided into two portions. One portion was air-dried for measuring soil pH and conducting soil organic carbon (SOC), soil total N (TN), and soil total phosphorus (TP) as says, and the other portion was stored in a refrigerator for measuring soil microbial biomass carbon (MBC), NH$_4^+$, and NO$_3^−$. Briefly, soil pH was measured in a soil:water ratio of 1:2.5 using a pH meter (Li et al. 2016). Soil SOC and TN concentrations were determined using an elemental analyzer (Elementar Vario EL III; Germany). Soil TP was extracted using a Bray-2 solution (Bray 1945) and determined using the molybdate blue colorimetric method. Soil MBC was estimated using the chloroform-fumigation extraction method (Bao 2000). Samples were extracted with a 2-mol·L$^{-1}$ KCl solution, and the concentrations of NH$_4^+$ and NO$_3^−$ were determined using a Dionex ICS 1500 ion chromatographer (Dionex Corp. Atlanta, GA).

**Statistical analysis**

Data analyses were performed using SPSS 22.0 (SPSS Inc., Chicago, IL, USA) for Windows. One-way analysis of variance (ANOVA) and least significant difference multiple comparisons were used to identify significant differences in $Q_{10}$, GWP, and soil CO$_2$, CH$_4$, and N$_2$O fluxes. Two-way ANOVA was used to test the significance of the interaction between N addition and management scheme for the variation in soil CO$_2$, CH$_4$, and N$_2$O fluxes. All data were tested for homogeneity of variance and distribution normality before conducting the ANOVA. In addition, Pearson’s correlation analyses between soil characterization and soil CO$_2$, CH$_4$, and N$_2$O fluxes were conducted.

**Results**

**Soil GHG fluxes**

The seasonal variation of soil CO$_2$ flux showed the same pattern in all treatments, peaking in summer and reaching a trough in winter (Fig. 1). Compared with CM, IM significantly promoted annual soil CO$_2$ emissions by 7.5%. Compared with the control treatment, N30 and N60 significantly promoted annual soil CO$_2$ emissions by 31.7% and 22.1% in CM plots, and by 34.0% and 20.9% in IM plots, respectively, while N90 had no significant effect on annual soil CO$_2$ emissions in either CM or IM plots (Fig. 1). Management scheme had no significant effect on annual soil CH$_4$ uptake. Compared with the control treatment, N30 had no significant effect on annual soil CH$_4$ uptake in either CM or IM plots, but
Fig. 1 Soil CO₂ emission rates under different N addition treatments (control, 0 kg N·ha⁻¹·year⁻¹; N30, 30 kg N·ha⁻¹·year⁻¹; N60, 60 kg N·ha⁻¹·year⁻¹; N90, 90 kg N·ha⁻¹·year⁻¹) in plots under conventional management (CM, a) or intensive management (IM, b) and annual soil CO₂ emissions (c) from a Moso bamboo plantation (mean ± standard deviation, n = 3). Lowercase letters indicate differences in soil CO₂ emissions under different N addition treatments in CM plots (P < 0.05). Uppercase letters indicate differences in soil CO₂ emissions under different N addition treatments in IM plots (P < 0.05). The asterisk indicates differences in soil CO₂ emissions between different management schemes under the same N addition treatment (P < 0.05).

Fig. 2 Soil CH₄ emission rates of different N addition treatments (control, 0 kg N·ha⁻¹·year⁻¹; N30, 30 kg N·ha⁻¹·year⁻¹; N60, 60 kg N·ha⁻¹·year⁻¹; N90, 90 kg N·ha⁻¹·year⁻¹) in plots under conventional management (CM, a) or intensive management (IM, b) and annual soil CH₄ emissions (c) from a Moso bamboo plantation (mean ± standard deviation, n = 3). Lowercase letters indicate differences in soil CH₄ emissions under different N addition treatments in CM plots (P < 0.05). Uppercase letters indicate differences in soil CH₄ emissions under different N addition treatments in IM plots (P < 0.05).
N60 and N90 significantly inhibited annual soil CH4 uptake by 23.6% and 27.1% in CM plots, respectively (Fig. 2).

The dynamics of annual soil N2O emission rates were not significantly affected by management scheme, but N addition caused N2O emission rates to peak from March to April (Fig. 3). In CM plots, compared with the control treatment, N30 did not significantly affect annual soil N2O emissions, while N60 and N90 significantly promoted annual soil N2O emissions by 52.7% and 47.0%, respectively (Fig. 3). On the contrary, in IM plots, compared with control treatment, N30, N60, and N90 significantly promoted annual soil N2O emissions by 61.3%, 69.2%, and 49.3%, respectively. Two-way ANOVA showed that N addition or management scheme independently had significant effects on soil CO2 emissions, CH4 uptake, and N2O emissions, but the interactions between them did not (Table S1).

The Q10 value of soil CO2 efflux varied from 1.89 to 2.37 under the different treatments combining management scheme and N addition (Table S2). IM significantly increased the Q10 value by 11.3% relative to that in CM when no N was added. N addition had no significant effect on the Q10 value in CM plots but significantly decreased the Q10 value in IM plots (Table S2). Furthermore, the significantly higher Q10 value in IM than in CM plots under no N addition treatments decreased under both N60 and N90 treatments (Table S2).

Soil CO2 flux was significantly and positively correlated with soil MBC and TP concentrations but significantly and negatively correlated with soil SOC and TN concentrations, and C/N ratio (P < 0.05, Table 2). Soil CH4 flux significantly and negatively correlated with soil MBC, TP, and NH4+ concentrations (P < 0.05, Table 2). Soil N2O flux was significantly and positively correlated

Table 2 Pearson correlation coefficients between soil physicochemical properties and CO2, CH4, and N2O fluxes

|                  | MBC   | SOC   | TN    | TP    | C/N   | pH   | NO3− | NH4+ |
|------------------|-------|-------|-------|-------|-------|------|------|------|
| CO2 fluxes       | 0.430 | 0.814 | 0.606 | 0.529 | −0.291 | 0.261| −0.035| 0.200|
| CH4 fluxes       | −0.374| −0.065| −0.247| −0.325| 0.144 | −0.082| −0.114| −0.290|
| N2O fluxes       | 0.334 | −0.172| 0.267 | 0.092 | −0.409 | −0.237| 0.621 | 0.178|

MBC soil microbial biomass carbon; SOC soil organic carbon content; TN total nitrogen; TP total phosphorus. ** P < 0.01, * P < 0.05
with soil MBC and NO$_3^-$ concentrations and negatively correlated with C/N ratio and pH ($P < 0.05$, Table 2).

**Annual GWP of soil GHG fluxes**

Annual GWP owing to soil CO$_2$, CH$_4$, and N$_2$O emissions was $34.88 \pm 1.19$ t CO$_2$eq·ha$^{-1}$ in the Moso bamboo plantations under CM and without N addition (Fig. 4). Compared with CM, IM significantly increased the annual GWP by 7.98%. Furthermore, compared with the control treatment, N30 and N60 significantly increased the annual GWP by 31.5% and 23.7% in CM plots, and by 35.6% and 23.6% in IM plots, respectively, while N90 had no significant impact on the annual GWP under either CM or IM treatments.

**Discussion**

**Effect of management scheme on soil CO$_2$, CH$_4$, and N$_2$O emissions**

We observed that the mean annual soil CO$_2$, CH$_4$, and N$_2$O emission rates in control plots under CM were $9106.09 \pm 297.15$ kg CO$_2$-C·ha$^{-1}$·year$^{-1}$, $-3.98 \pm 0.12$ kg CH$_4$-C·ha$^{-1}$·year$^{-1}$, and $3.48 \pm 0.46$ kg N$_2$O-N·ha$^{-1}$·year$^{-1}$, respectively (Table S3). Our study showed that the mean annual soil CO$_2$ emission rate in the Moso bamboo forest was higher than that of boreal forests ($3220 \pm 310$ kg CO$_2$-C·ha$^{-1}$·year$^{-1}$), temperate coniferous forests ($6810 \pm 950$ kg CO$_2$-C·ha$^{-1}$·year$^{-1}$), deciduous forests ($6470 \pm 510$ kg CO$_2$-C·ha$^{-1}$·year$^{-1}$; Raich and Schlesinger 1992), subtropical bitter bamboo (*Pleioblastus amarus*) ($4280 \pm 110$ kg CO$_2$-C·ha$^{-1}$·year$^{-1}$; Tu et al. 2013), and Chinese fir (*Cunninghamia lanceolata*) forests ($6637.36 \pm 581.24$ kg CO$_2$·ha$^{-1}$·year$^{-1}$; Wang et al. 2018); however, it was lower than the corresponding rate in subtropical evergreen broad-leaved forests ($11,509.09 \pm 463.64$ kg CO$_2$·C·ha$^{-1}$·year$^{-1}$; Liu et al. 2011) and tropical moist forests ($12,600 \pm 570$ kg CO$_2$·C·ha$^{-1}$·year$^{-1}$; Raich and Schlesinger 1992). The mean annual soil CH$_4$ emission rate in this study was similar to that in mid-subtropical nature forests ($-4.13 \pm 0.44$ kg CH$_4$·C·ha$^{-1}$·year$^{-1}$; Chen et al. 2014) but lower than that in typical tropical montane rainforests ($-1.93 \pm 0.15$ kg CH$_4$·C·ha$^{-1}$·year$^{-1}$; Yang et al. 2018), evergreen broad-leaved forests ($-1.90$ kg CH$_4$·C·ha$^{-1}$·year$^{-1}$; Fang et al. 2009), larch plantations ($-0.54$ kg CH$_4$·C·ha$^{-1}$·year$^{-1}$; Kim et al. 2012), and Korean pine forests ($-0.05$ kg CH$_4$·C·ha$^{-1}$·year$^{-1}$; Song et al. 2017a). The mean annual soil N$_2$O emission rate in this study was higher than that of typical tropical montane rainforests ($1.67 \pm 0.04$ kg N$_2$O·N·ha$^{-1}$·year$^{-1}$; Yang et al. 2018), larch (*Larix kaempferi*) plantations ($1.13$ kg N$_2$O·N·ha$^{-1}$·year$^{-1}$; Kim et al. 2012), and Korean pine (*Pinus koraiensis*) forests ($1.11$ kg N$_2$O·N·ha$^{-1}$·year$^{-1}$; Song et al. 2017a) but was lower than that of evergreen broad-leaved forests ($6.00$ kg N$_2$O·N·ha$^{-1}$·year$^{-1}$; Fang et al. 2009) and three subtropical forests ($6.40 \pm 2.41$ kg N$_2$O·N·ha$^{-1}$·year$^{-1}$; Tang et al. 2006). Overall, compared with other subtropical forests, bamboo forest soils under CM showed lower CO$_2$, CH$_4$, and N$_2$O emission rates, which have a significant positive effect in decreasing the GWP of soil GHG emissions.

We found that IM significantly increased annual CO$_2$ emissions, which partially supports our first hypothesis and was consistent with the results of Liu et al. (2011) in
Moso bamboo forests. However, some studies indicate that the state box method using linear fitting will cause an underestimation of soil CO₂ efflux (Wang 2005; Luo and Zhou, 2006). Therefore, the real soil CO₂ efflux may be greater in the Moso bamboo plantation. Soil CO₂ efflux mainly comprises root respiration and microbial respiration (Coleman 1973). IM practices, such as fertilization, stimulate root respiration (Jassal et al. 2010; Mori et al. 2013; Tang et al. 2016). Concomitantly, ploughing disaggregates soil and releases protected SOC (Sainju et al. 2008; Li et al. 2013; Tivet et al. 2013), which provides more substrate for microbial respiration, and the decomposition of protected SOC can increase soil CO₂ emissions. Meanwhile, fertilization increases soil MBC by providing abundant nutrients for microbial growth (Li et al. 2016) and accelerates the decomposition of organic matter by heterotrophic microorganisms (Cleveland et al. 2002; Ilstedt et al. 2003), resulting in a decrease in SOC concentration (Ma et al. 2011) and promotion of soil CO₂ emissions (Tu et al. 2013). We observed that soil CO₂ flux was significantly and positively correlated with soil MBC and significantly and negatively correlated with SOC (Table 2). IM had no significant effect on annual CH₄ uptake or N₂O emissions, which partially supports our first hypothesis regarding the fluxes of these two gases, i.e., IM does not affect soil N₂O emissions or CH₄ uptake. Previous studies have also shown that management does not affect soil CH₄ uptake or N₂O emissions (Whalen and Reeburgh 2000; Jassal et al. 2010; Zhang et al. 2015). The response of soil N₂O emissions to external environmental factors and the influence on soil CH₄ uptake were determined to be the major reasons for the differences observed in soil GHG emissions (Yan et al. 2014). Some studies found that applying N fertilizer could stimulate soil N₂O emissions in farmland soil (Jäger et al. 2013) and vineyard soil (Tatti et al. 2012). However, compared with CM, IM did not significantly increase soil N₂O emissions (Fig. 3), which may be attributed to infrequent fertilization (once a year).

The Q₁₀ value reflects the temperature dependence of soil CO₂ efflux, calculated from a series of soil CO₂ efflux measurements over a time period while soil temperature changes (Rey et al. 2002; Ma et al. 2014). The Q₁₀ value of the soil CO₂ efflux in plantations under CM is 2.13, which is close to the Q₁₀ value of Moso bamboo forests in the Wannulin Natural Reserve (2.08; Wang et al. 2011) and the average Q₁₀ of bamboo forests in China (2.10; Song et al. 2014). Compared with CM, IM significantly increased the Q₁₀ of soil CO₂ efflux (Table S2). Tang et al. (2016) observed the same result and concluded that the main reason might be the increase in Q₁₀ of soil microbial respiration. In the present study and the previous study on the same site, IM significantly increased soil MBC (Table S4; Li et al. 2016). Moreover, a significant positive correlation between soil CO₂ flux and soil MBC was found in this study (Table 2), which supports the conclusion of Tang et al. (2016). Li et al. (2020) have found that root respiration does not affect Q₁₀ of soil CO₂ efflux in forest ecosystems.

Compared with CM, IM significantly increased the annual GWP in Moso bamboo plantations (Fig. 4), which can be mainly attributed to the increase in CO₂ emissions (Table S5). The results suggest that IM induces greater GHG emissions from soils than CM did, although IM may enhance the productivity of Moso bamboo plantations (Zhou et al. 2010). Therefore, the benefits of IM to Moso bamboo plantations need further comprehensive evaluation, especially in the scenarios of increasing atmospheric N deposition.

**Effect of N addition on soil CO₂, CH₄, and N₂O fluxes**

In this study, N addition enhanced CO₂ emissions in both CM and IM plots, which partially supports our second hypothesis, i.e., N addition promotes CO₂ emissions. Tu et al. (2009) observed that simulated N deposition promoted soil CO₂ emission in a bitter bamboo plantation. Some short-term simulated N deposition studies have also shown similar results (Madritch and Hunter 2003; Mo et al. 2005; Song et al. 2007). Soil CO₂ emissions are related to above-ground biomass, litter mass, underground root biomass, and soil biological factors (e.g., microorganisms and animals) (Zhang et al. 2008a). Our previous studies showed that N input increased the amount of leaf litter (Zhang et al. 2017), decomposition of leaf litter (Song et al. 2015), fine root litter (Song et al. 2017c), and soil microbial biomass (Li et al. 2016) in the current study site, all of which contributed to oxidizing organic C to CO₂ (Steudler et al. 1991; Emmett 1999), thus increasing CO₂ emissions. In this study, soil MBC significantly and positively correlated with CO₂ flux (Table 2), which supports the conclusion that N addition increased soil CO₂ emissions by increasing MBC. However, Li et al. (2017) found that the CO₂ emissions of the Moso bamboo forest soil did not change after N addition (40 kg N·ha⁻¹·yr⁻¹ KNO₃) in their incubation experiment, which was different from our experimental results. This difference may be owing to the difference in N source, the external environment of the experiment, and the processing time.

N addition significantly inhibited soil CH₄ uptake in CM, which supports our second hypothesis, i.e., N addition decreases CH₄ uptake in CM. Similar results have been observed in a Douglas fir stand (Jassal et al. 2011) and a young Japanese larch plantation (Kim et al. 2012). Soil CH₄ uptake rate is usually negatively correlated with soil NH₄⁺ concentration (Zhang et al. 2012),...
as was observed in this study (Table 2). The inhibitory effect of NH₄⁺ on soil CH₄ oxidation can be attributed to the production of the intermediates, hydroxylamine and NO₂⁻, during the nitrification of NH₄⁺, which likely inhibits the activity of methane-oxidizing bacteria, thereby extending the inhibition time (Nyerges and Stein 2009). Further, low pH can reduce the activity of methane-oxidizing bacteria (Semenov et al. 2004), because soil acidification may increase the concentration of Al³⁺ in the forest soil solution, while Al³⁺ ions have an obvious toxic effect on CH₄-oxidizing bacteria (Nanba and King 2000; Tamai et al. 2007).

In this study, N addition (N60 and N90) significantly increased N₂O emissions, which partially supports our second hypothesis, i.e., N addition increases soil N₂O emissions. Similar results were observed in a young Japanese larch forest (Kim et al. 2012) and in incubated Moso bamboo forest soil (Li et al. 2017). N input can increase soil N availability, nitrification, and denitrification and, thus, increase N₂O emissions (Repo et al. 2009). N addition decreased soil pH significantly (Table S4), while NO₂⁻ may have induced aerobic denitrification in acidic soils (Mørkved et al. 2007), thereby increasing N₂O emissions. A significant negative correlation between soil pH and soil N₂O flux was found in this study (Table 2). N addition increased soil total N content and, thus, decreased the soil C/N ratio (Li et al. 2019), which is beneficial for the proportion of external N input converted to N₂O (Zhang et al. 2008a). Similarly, a significant negative correlation between soil C/N ratio and soil N₂O flux was found in this study (Table 2).

N addition had no effect on Q₁₀ of soil CO₂ efflux relative to that in the control treatment in plots under CM but significantly decreased Q₁₀ value in IM plots (Table S2). Similar results have been reported by Mo et al. (2007), who found three-year high-N addition (150 kg N·ha⁻¹·year⁻¹) reduced Q₁₀ values in a mature tropical forest. Tu et al. (2013) also observed that N addition decreased Q₁₀ of soil CO₂ efflux in a bamboo ecosystem in southwestern China. Karhu et al. (2014) suggested that microbial community responses increase the temperature sensitivity of soil heterotrophic respiration. Our previous studies have shown that, although N addition significantly increased soil MBC, it also decreased soil pH (Li et al. 2016), which might result in microbial activity being inhibited by soil acidity (Kunito et al. 2016). This, in turn, may hamper the microbial community responses, whereby the microbial community has no effect on the temperature sensitivity of soil CO₂ efflux. Furthermore, our previous studies have shown that increases in soil MBC are inhibited when N addition exceeds 60 kg N·ha⁻¹·yr⁻¹ (Li et al. 2016). We suspect that N input from N addition and N fertilizer in IM treatments inhibited any increase in soil MBC and even reduced soil MBC. This might be why N addition did not affect the temperature sensitivity of soil CO₂ efflux under CM, yet it reduced the Q₁₀ value in the plots under IM.

The GWP of a GHG is a measure of how much energy the emissions of 1 kg of a gas will absorb over a given period of time relative to that absorbed by the emissions of 1 kg of CO₂ (Tian et al. 2015). The larger the GWP, the more that a given gas warms the Earth compared with CO₂ over that time period. Moderate N addition significantly increased annual GWP of soil GHG fluxes in both CM and IM plots, which is mainly attributed to the increase in annual soil CO₂ emissions. Annual soil CH₄ uptake and N₂O emissions did not significantly affect annual GWP. The reason was that the GWP values of CH₄ and N₂O were much larger than that of CO₂ (25 and 298 times, respectively), but the annual soil CH₄ uptake and N₂O emissions were only 0.12%–0.18% and 0.16%–0.31% of the annual CO₂ emissions, respectively.

In addition, IM enhanced soil CO₂ and N₂O emissions under low N addition (N30), which partly supports our third hypothesis, i.e., IM promotes soil CO₂ and N₂O emissions under N addition. The finding that IM provides more N input may be why IM significantly increased soil CO₂ and N₂O emissions under low N addition. IM did not affect soil CH₄ uptake under N addition, which was consistent with the effect on plots without N addition, but it did not support our third hypothesis that IM inhibits soil CH₄ uptake under N addition. This may due to the combination of IM and N addition offsetting the inhibitory effect of N addition on soil CH₄ uptake. In summary, IM significantly increased GWP under low N addition owing to the main contribution of CO₂ emissions to GWP.

**Conclusion**

Compared with CM, IM significantly increased the GWP of soil GHG emissions and sensitivity of soil CO₂ efflux to soil temperature (Q₁₀), mainly owing to an increase in soil CO₂ emissions. Nitrogen deposition (≤60 kg N·ha⁻¹·year⁻¹) significantly increased soil CO₂ and N₂O emissions but inhibited CH₄ uptake, which resulted in a significant increase in GWP. However, N addition (> 60 kg N·ha⁻¹·year⁻¹) decreased all soil CO₂ and N₂O emissions and CH₄ uptake. Concomitantly, the Q₁₀ value of soil CO₂ efflux was significantly reduced after N addition in plots under IM, which indicates that N addition might mitigate the effect of future climate warming on soil CO₂ efflux in intensively managed Moso bamboo plantations. Soil MBC correlated significantly and positively with soil CO₂ and N₂O fluxes but correlated negatively with soil CH₄ fluxes, indicating that soil microbes have a strong influence on soil GHG emissions. These results demonstrate that management scheme and N application influenced the GWP of the Moso bamboo plantation ecosystem under study.
Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s40466-021-02285-0.

Additional file 1: Table S1. Two-way ANOVA of the effects of nitrogen (N) addition and management scheme on soil CO₂, CH₄, and N₂O fluxes in a Moso bamboo forest. Table S2 Sensitivities of soil CO₂ efflux to soil temperature (Q₁₀) at a depth of 5 cm. Table S3 Annual soil CO₂, N₂O and CH₄ emissions calculated in different treatment plots. Table S4 Soil physicochemical properties under different treatments (mean ± standard error, n = 12). Table S5 CO₂ emission, N₂O emission and CH₄ uptake contribution to GWP in different treatment plots.

Acknowledgements
Many thanks are due to Honghao Gu and others for participation or help in the data collection.

Authors’ contributions
Xinzhang Song and Changhui Peng designed research, Junbo Zhang and Quan Li performed research, collected and analyzed data; All authors discussed the results and revised the manuscript. The author(s) read and approved the final manuscript.

Funding
This study was funded by the National Natural Science Foundation of China (Grant Nos. 31270517 and 31470529).

Availability of data and materials
The datasets used and/or analyzed in this study are available from the corresponding author on request.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
All authors have no conflict of interest.

Author details
1State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Hangzhou 311300, China. 2Department of Biology Sciences, Institute of Environment Sciences, University of Quebec at Montreal, Case Postale 8888, Succursale Centre-Ville, Montreal H3C 3P8, Canada. 3Huzhou Research Institute of Forestry, Huzhou 313000, China. 4International Centre for Bamboo and Rattan, Beijing 100102, China. 5Zhejiang Academy of Forestry, Hangzhou 310023, China.

Received: 9 June 2020 Accepted: 13 January 2021

Published online: 02 February 2021

References
Bao SD (2000) Soil and agricultural chemistry analysis, 3rd edn. Chinese Agriculture Press, Beijing
Bowden RD, Davidson E, Savaga K, Arabia C, Steudler P (2004) Chronic nitrogen additions reduce total soil respiration and microbial respiration in temperate forest soils at the Harvard Forest. Forest Ecol Manag 196:43–56
Bray HR (1945) Soil-plant relations: II. Balanced fertilizer use through soil tests for potassium and phosphorus. Soil Sci 60:463–474
Chen CQ, Yang ZJ, Liu XF, Wu JJ, Huang YM (2014) Responses of CH₄ uptake rates to simulated N deposition in a nature forest in mid-subtropical China. Acta Ecol Sin 34:2498–2508 (in Chinese)
Cleveland C, Townsend A, Schmidt S (2002) Phosphorus limitation of microbial processes in moist tropical forests: evidence from short-term laboratory incubations and field studies. Ecosystems 5:680–691
Coleman DC (1973) Compartamental analysis of "total soil respiration": an exploratory study. Oikos 24:361–366
Cusack DF, Silver WL, Tom MS, McDowell WH (2011) Effects of nitrogen additions on above- and belowground carbon dynamics in two tropical forests. Biogeochemistry 104:203–225
Deng L, Huang CB, Kim DG, Shangguan ZP, Wang KB, Song XZ, Peng CH (2020) Soil GHG fluxes are altered by N deposition: new data indicate lower N stimulation of the N₂O flux and greater stimulation of the calculated C pools. Glob Chang Biol 26:2613–2629
Emmett BA (1999) The impact of nitrogen on forest soils and feedbacks on tree growth. Water Air Soil Poll 116:65–74
Fang YT, Gundersen P, Zhang W, Zhou GY, Christiansen JR, Mo JM, Dong SF, Zhang T (2009) Soil-atmosphere exchange of N₂O, CO₂, and CH₄ along a slope of an evergreen broad-leaved forest in southern China. Plant Soil 319:37–48
FAO (2005) Proceedings FAO advisory committee on paper and wood products. Food and Agricultural Organisation of the United Nations: Forty-sixth Session, Vancouver
Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nzunga J, Prinn R, Raga M, Schulz M, Dorland RH (2007) Changes in atmospheric constituents and in radiative forcing. In: Solomon S (ed) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, UK, pp 130–234
Galloway JN, Dentener FJ, Capone DG, Boyer EW, Howarth RW, Seitzinger SP, Asner GP, Cleveland CC, Green PA, Holland EA, Karl DM, Michaels AF, Porter JH, Townsend AR, Vobrtsmaj C (2004) Nitrogen cycles: past, present and future. Biogeochemistry 70:153–226
Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, Martellin LA, Seitzinger SP, Sutton MA (2008) Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320:889–892
Gao Q, Hasselquist NJ, Palmroth S, Zheng ZM, You WH (2014) Short-term response of soil respiration to nitrogen fertilization in a subtropical evergreen forest. Soil Biol Biochem 76:297–300
Geng J, Cheng SL, Fang HJ, Yu GR, Li XY, Si GY, He S, Yu GX (2017) Soil nitrate accumulation explains the nonlinear responses of soil CO₂ and CH₄ fluxes to nitrogen addition in a temperate needle-broadleaved mixed forest. Ecol Indic 79:26–36
Gulledge J, Hryvyna Y, Cavanaugh CA, Steudler PA (2004) Effects of long-term nitrogen fertilization on the uptake kinetics of atmospheric methane in temperate forest soils. FEMS Microbiol Ecol 49:389–400
Ilstedt U, Giesler R, Nordgren A, Malmer A (2003) Changes in soil chemical and microbial properties after a wildfire in a tropical rainforest in Sabah, Malaysia. Soil Biol Biochem 35:1078–1087
IPCC (2013) Climate change 2013: the physical science basis. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, UK and New York https://books.google.co.uk/books?id=ep0142. Accessed 15 October 2020
Jäger N, Duffner A, Ludwig B, Flessa H (2013) Effect of fertilization history on short-term emission of CO₂ and N₂O after the application of different N fertilizers – a laboratory study. Arch Agron Soil Sci 59:161–171
Jassal RS, Black TA, Roy R, Ething G (2011) Effect of nitrogen fertilization on soil CH₄ and N₂O fluxes, and soil and bole respiration. Geoderma 162:88–99
Jassal RS, Black TA, Trofymow JA, Roy R, Niesic Z (2010) Soil CO₂ and N₂O flux dynamics in a nitrogen-fertilized Pacific Northwest Douglas-fir stand. Geoderma 157:118–125
Karhu K, Auffret MD, Dungait JAJ, Hopkins DW, Prosser JI, Singh BK, Subke JA, Asner GP, Cleveland CC, Green PA, Holland EA, Karl DM, Michaels AF, Porter JH, Townsend AR, Vobrtsmaj C (2004) Contributions to GWP in different treatment plots.
Kunito T, Isomura I, Sumi H, Park H, Toda H, Otsuka S, Nagaoka K, Saelk K, Senoo K (2016) Aluminium and acidity suppress microbial activity and biomass in acidic forest soils. Soil Biol Biochem 97:23–30
Zhang T (2009) Soil-atmosphere exchange of N₂O, CO₂ and CH₄ along a slope of an evergreen broad-leaved forest in southern China. Plant Soil 319:37–48
Lei L, Zhang XY, Wang SQ, Lu XH, Ouyang XY, Hong YG (2016) A review of spatial variation of inorganic nitrogen (N) wet deposition in China. PLoS One 11:e0146051

Li JQ, Pendall E, Djikstra FA, Nie M (2020) Root effects on the temperature sensitivity of soil respiration depend on climatic condition and ecosystem type. Soil Till Res 199:104574

Li Q, Song XZ, Chang SX, Peng CH, Xiao WF, Zhang JB, Xiang WH, Li Y, Wang WF (2019) Nitrogen depositions increase soil respiration and decrease temperature sensitivity in a Moso bamboo forest. Agr For Meteorol 268:48–54

Li Q, Song XZ, Gu HH, Gao F (2016) Nitrogen deposition and management practices increase soil microbial biomass carbon but decrease diversity in Moso bamboo plantations. Sci Rep 6:26825

Li XY, Cheng SL, Fang HJ, Yu GR, Dang XS, Xu MJ, Wang L, Si GY, Geng J, He S (2015) The contrasting effects of deposited NH₄⁺ and NO₃⁻ on soil CO₂, CH₄ and N₂O fluxes in a subtropical plantation, southern China. Ecol Eng 85:317–327

Li YF, Zhang J, Chang SX, Jiang PK, Zhou GM, Fu SL, Yan ER, Wu JS, Lin L (2013) Long-term intensive management effects on soil organic carbon pools and chemical composition in Moso bamboo (Phyllostachys pubescens) forests in subtropical China. Forest Ecol Manag 303:121–130

Li ZZ, Zhang L, Deng BL, Liu YQ, Kong FQ, Huang GX, Zou Q, Liu Q, Guo XM, Fu YQ, Niu DK, Siemann E (2017) Effects of moso bamboo (Phyllostachys edulis) invasions on soil nitrogen cycles depend on invasion stage and warming. Environ Sci Pollut Res 24:2489–2499

Liu HM, Zhou GY, Bai SH, Song JI, Jiang SY, He M, Wang XH, Zheng ZM (2019) Differential response of soil respiration to nitrogen and phosphorus addition in a highly phosphorus-limited subtropical forest, China. Forest Ecol Manag 448:499–508

Liu J, Jiang PK, Wang HL, Zhou GM, Wu JS, Yang F, Qian XB (2011) Seasonal soil CO₂ flux dynamics after land use change from a natural forest to Moso bamboo plantations in subtropical China. Forest Ecol Manag 262:1131–1137

Liu LL, Geaever TL (2009) A review of nitrogen enrichment effects on three biogenic GHGs: the CO₂ sink may be largely offset by stimulated N₂O and CH₄ emission. Ecol Lett 12:1103–1117

Liu XJ, Zhang Y, Han WX, Tang A, Shen JL, Cui ZL, Vitousek P, Erisman JW, Shi J, Bai J (2019) Effects of N deposition on leaf litter decomposition of the Moso bamboo (Phyllostachys pubescens) forests in central China. Ecol Res 22:649–2057

Mori T, Ohta S, Ishizuka S, Konda R, Wicaksono A, Heriyanto J, Hamotani Y, Mørkved PT, Dorsch P, Bakken LR (2007) The N₂O product ratio of nitriﬁcation and its dependence on long-term changes in soil pH. Soil Biol Biochem 39:2048–2057

Müller AK, Matson AL, Corre MD, Veldkamp E (2015) Soil N₂O fluxes along an elevation gradient of tropical montane forests under experimental nitrogen and phosphorus addition. Front Earth Sci 3:669

Ntaba K, King GM (2000) Response of atmospheric methane consumption by Maine forest soils to exogenous aluminum salts: Appl Environ Microbiol 66:3674–3679

Nyerges G, Stein LY (2009) Ammonia compostabilum and product inhibition vary considerably among species of methanotrophic bacteria. FEMS Microbiol Lett 297:131–136

Reich JW, Schlesinger WH (1992) The global carbon dioxide ﬂux in soil respiration and its relationship to vegetation and climate. Tellus B 44:81–99

Rey DS, Dentener F, Smith P, Grace J, Feely RA (2008) Global nitrogen deposition and carbon sinks. Nat Geosci 1:430–437

Repe MO, Susiluoto S, Lind SE, Jokinen S, Elsavok V, Biasi C, Virtanen T, Martikainen PJ (2009) Large N₂O emissions from cryoturbated peat soil in tundra. Nat Geosci 2:189–192

Rey A, Pegoaro E, Tedeschi V, De Panti I, Janvis PG, Valentinii R (2002) Annual variation in soil respiration and its components in a coppice oak forest in Central Italy. Glob Chang Biol 8:851–866

Sainju UM, Jabro JD, Stevens WB (2008) Soil carbon dioxide emission and carbon content as affected by irrigation, tillage, cropping system, and nitrogen fertilization. J Environ Qual 37:98–106

Semenov VM, Kravchenko R, Kuznetsova TV, Semenova NA, Bykova SA, Dulov LE, Gafchentko VF, Pardini G, Gispert M, Boeckx P, van Cleemput O (2004) Seasonal dynamics of atmospheric methane oxidation in gray forest soils. Microbiology 73:356–362

Staaka BK, Bakken LR, Abrahamsen G (1995) CH₄ uptake by temperate forest soil: effect of N input and soil acidification. Soil Biol Biochem 27:871–880

Song L, Tian P, Zhang JB, Jin GZ (2017a) Effects of three years of simulated nitrogen deposition on soil nitrogen dynamics and greenhouse gas emissions in a Korean pine plantation of Northeast China. Sci Total Environ 609:1301–1311

Song XG, Hu TX, Xian JR, Xiao CL, Liu WT (2007) Soil respiration and its response to simulated nitrogen deposition in evergreen broad-leaved forest, Southwest Schuan. J Soil Water Conserv 21:168–172 (in Chinese)

Song XZ, Chen XF, Zhou GM, Jiang H, Peng CH (2017b) Observed high and persistent carbon uptake by Moso bamboo forests and its response to environmental drivers. Agr For Meteorol 247:467–475

Song XZ, Li Q, Gu HH (2017c) Effect of nitrogen deposition and management practices on fine root decomposition in Moso bamboo plantations. Plant Soil 410:207–215

Song XZ, Peng CH, Ciais P, Li Q, Xiang WH, Xiao WF, Zhou GM, Deng L (2020) Nitrogen addition increased CO₂ uptake more than non-CO₂ greenhouse gas emissions in a Moso bamboo forest. Sci Adv 6:90

Song XZ, Peng CH, Zhao YZ, Zhang GT, Guo BH, Wang WF, Jiang H, Zhu QA (2014) Quantification of soil respiration in forest ecosystems across China. Atmos Environ 94:456–451

Song XZ, Zhou GM, Gu HH, Qi LH (2015) Management practices amplify the effects of N deposition on leaf litter decomposition of the Moso bamboo forest. Plant Soil 395:391–400

Steudler PA, Melillo JM, Bowden RD, Castro MS, McGuire AD, Lugo AE, Melillo JM, Bowden RD, Castro MS, McGuire AD, Lugo AE (1991) The effects of air pollution on soil carbon and nitrogen cycling in forest ecosystems of Central Italy. Glob Chang Biol 8:851–866

Sun LY, Li L, Chen ZZ, Wang JY, Xiong ZQ (2014) Combined effects of nitrogen addition and biochar application on emissions of N₂O, CO₂ and NH₃ from agricultural and forest soils. Soil Sci Plant Nutr 60:254–265

Tamai N, Takenaka C, Ishizuka S (2007) Water-soluble Al inhibits methane oxidation at atmospheric concentration levels in Japanese forest soil. Soil Biol Biochem 39:172–178

Tang XL, Fan SH, Qi LH, Guan FY, Du MY, Zhang H (2016) Soil respiration and net ecosystem production in relation to intensive management in Moso bamboo forests. Catena 137:219–228

Tang XL, Liu SG, Zhou GY, Deng L (2020) Soil-atmospheric exchange of CO₂, CH₄ and N₂O in three subtropical forest ecosystems in southern China. Glob Chang Biol 12:546–560
Tatti E, Goyer C, Zebart B, Viti C, Giovannetti L, Burton DL (2012) Short-term effects of mineral and organic fertilizer on denitrifiers, nitrous oxide emissions and denitrification in long-amended vineyard soils. Soil Sci Soc Am J 77:113–122

Tian HQ, Chen GS, Lu CQ, Xu XF, Haydes DJ, Ren W, Pan SF, Huntzinger DN, Wofsy SC (2015) North American terrestrial CO2 uptake largely offset by CH4 and N2O emissions: toward a full accounting of the greenhouse gas budget. Clim Chang 129:413–426

Tian HQ, Chen GS, Lu CQ, Xu XF, Ren W, Zhang B, Banger K, Tao B, Pan SF, Liu ML, Zhang C, Bruhwiler L, Wofsy S (2016) Global methane and nitrous oxide emissions from terrestrial ecosystems due to multiple environmental changes. EHS 1:1–20

Tian J, Dungait JA, Lu XK, Yang YF, Hartley LP, Zhang W, Mo JM, Yu GR, Zhou JZ, Kuyakov Y (2019) Long-term nitrogen addition modifies microbial composition and functions for slow carbon cycling and increased sequestration in tropical forest soil. Glob Chang Biol 25:3267–3281

Tivet F, Sá JC, Lai R, Bredis C, Borszowszki PR, Santos JBD, Farias A, Eurch G, Hartman DDC, Junior MN, Bouzinac S, Séguy L (2013) Aggregate C depletion by plowing and its restoration by diverse biomass-C inputs under no-till in sub-tropical and tropical regions of Brazil. Soil Till Res 126:203–218

Tu LH, Hu TX, Huang LH, Li PH, Dai HZ, Luo SH, Xiang YB (2009) Response of soil respiration to simulated nitrogen deposition in Peltophorum pterocarpum forest, rainy area of West China. Chin J Plant Ecol 33:728–738 (in Chinese)

Tu LH, Hu TX, Zhang J, Li XW, Hu HL, Liu L, Xiao YL (2013) Nitrogen addition stimulates different components of soil respiration in a subtropical bamboo ecosystem. Soil Biol Biochem 58:255–264

Venterea RT, Groffman PM, Verchot LV, Magill AH, Aber JD, Steudler PA (2003) Nitrogen oxide gas emissions from temperate forest soils receiving long-term nitrogen inputs. Glob Chang Biol 9:346–357

Wang C, Yang ZJ, Chen GS, Fan YX, Liu Q, Tian H (2011) Characteristics of soil respiration in Phyllostachys edulis forest in Wanmulin natural reserve and related affecting factors. Chin J Appl Ecol 22:1212–1218 (in Chinese)

Wang FM, Li J, Wang XL, Zhang W, Zou B, Neher DA, Li ZA (2015) Nitrogen and phosphorus addition impact soil N2O emission in a secondary tropical forest of South China. Sci Rep-UK 4:5615

Wang YH (2005) Chamber method measurement of greenhouse gas emissions from typical terrestrial ecosystems of China: method research, application and results discussion. Dissertation, Institute of Atmospheric Physics, Chinese Academy of Sciences.

Wang YS, Cheng SL, Fang HJ, Yu GR, Xu MJ, Dang XS, Li LS, Wang L (2014) Simulated nitrogen deposition reduces CH4 uptake and increases N2O emission from a subtropical plantation forest soil in southern China. PLoS One 9:e93571

Wang YX, Zhu XD, Bai SB, Zhang T, Mulder J, Duan L (2012) Emissions of nitrous oxide from three tropical forests in southern China in response to simulated nitrogen deposition. Plant Soil 350:221–236

Zhang W, Zhu XM, Liu L, Fu SL, Chen H, Huang J, Lu XK, Liu ZF, Mo JM (2012) Large difference of inhibitive effect of nitrogen deposition on soil methane oxidation between plantations with N-fixing tree species and non-N-fixing tree species. J Geophys Res-Biogeo 117:G00N16

Zhang YF, Jiang J, Wang ZC, Chen LG, Zheng JC (2015) Nitrous oxide and methane emissions from a Chinese wheat-rice cropping system under different tillage practices during the wheat-growing season. Soil Till Res 146:261–269

Zhang S, Biao HF, Quan X, Xu L, Chen Z, He NP (2018) Effect of nitrogen and acid deposition on soil respiration in a temperate forest in China. Geoderma 329:82–90

Zhou GM, Jiang PK, Xu QF (2010) Carbon fixing and transition in the ecosystem of bamboo stands. Science Press, Beijing.