Response of soil fungal community in winter wheat to warming and fertilization regimes

Ning Han
Nanjing Agricultural University
Chaoran Yang
Nanjing Agricultural University
Mengting Liu
Nanjing Agricultural University
Xinyu Pei
Nanjing Agricultural University
Ruilin Mao
Nanjing Agricultural University
Changqing Chen (c0828@126.com)
Nanjing Agricultural University

Research Article

Keywords: nighttime warming, fertilization regimes, soil fungal, community diversity

Posted Date: December 20th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3771945/v1

Additional Declarations: No competing interests reported.

Response of soil fungal community in winter wheat to warming and fertilization regimes

Ning Han，Chaoran Yang，Mengting Liu，Xinyu Pei，Ruilin Mao，Changqing Chen*

Institute of Applied Ecology, Nanjing Agricultural University, Nanjing, Jiangsu 210095, PR China

Corresponding author.

E-mail address: c0828@126.com (C. Chen).

Abstract

Abstract: Understanding soil fungal diversity under global warming is significant for the assessment of climate change impacts on soil health and soil nutrient transformation. The interaction effect of warmer temperatures and fertilization regimes on fungal communities in the soils of winter wheat fields is unclear. Two-year potting experiments were conducted under nighttime warming and different fertilization regimes. The two-year continuous temperature increase significantly decreased the soil's pH. Warming and fertilization did not significantly change the dominant fungal phyla in the soil. However, it significantly increased the soil fungal richness and diversity compared with no warming and no fertilization. Warming increased richness and diversity by 4.15% and 4.24%, respectively, and fertilization increased richness and diversity by 14.15% and 4.27%, respectively. Furthermore, warming significantly increased the relative abundance of *Fusarium*, which is the causal agent of winter wheat weat root rot, from 1.75% to 3.62%. However, fertilization reduced the relative abundance of *Fusarium*, especially under the combined application of organic and inorganic fertilizers, suggesting that organic manure addition could impair soil fungal pathogens under future warming. The structural equation model demonstrated that the influence of soil temperature on fungal diversity was direct and mediated through soil carbon nitrogen ratios. Soil temperature and soil organic matter directly affected soil fungal diversity and were the most significant parameters influencing fungal diversity.

Keywords: nighttime warming; fertilization regimes; soil fungal; community diversity

Introduction

In the past few decades, with climate change, continuous global warming has led to rising global temperatures (Ye et al. 2020), which are expected to increase by 1.5℃ or more in the next 20 years. Global warming is highly variable, and asymmetric diurnal warming is one of the main features (Yan et al. 2017; Li et al. 2020). Asymmetric diurnal warming shows that the rate of global warming at night is higher than that in the daytime (Richard et al. 2017; Rossi et al. 2017). Fertilization is an important management measure in agricultural production that affects the physical and chemical properties of soil, thus affecting the quality and sustainable utilization of soil (Francioli et al. 2016; Zhang et al. 2015). The phenomenon of unreasonable fertilizer application structure in agricultural production is widespread, especially the emphasis on chemical fertilizers and neglect of organic fertilizers, the emphasis on nitrogen fertilizers and light phosphorus and potassium fertilizers, etc (Huang et al. 2020). In the long run, this may not only have caused a series of problems such as soil caking, soil acidification and soil nutrient imbalance (Guo and Wang. 2021), but also have altered soil microbial community composition and diversity (Campbell et al. 2010; Gu et al. 2019).

Fungi are critical microorganisms in soil ecosystems that play a fundamental ecological role as decomposers, symbionts or pathogens for plants and animals (Miao et al. 2016; Tedersoo et al. 2014), such as the formation and decomposition of soil organic matter, the recycling and utilization of nutrients, and the maintenance and improvement of soil fertility (Chen et al. 2019; Frąc et al. 2018). For example, there are symbiotic fungi that can form symbiotic relationships with crops. In addition, organic matter in the soil is decomposed by nutrient fungi which in turn release carbon into the soil. Fungi are also affected by temperature (Mateos-Rivera et al. 2016), pH (Liu et al. 2015), moisture (Watson et al. 2017), and soil nutrients (Pan et al. 2020). To date, some studies have been conducted to test the composition of fungal communities affected by warming and different fertilization regimes. Previous studies on the effects of warming on soil microbial community structure have yielded many different conclusions. Fungal community structure is altered by changes in temperature (Mucha et al. 2018). A small increase in temperature promotes respiration in the roots of the crop and will promote crop growth (Song et al. 2018), which in turn will affect the percentage of fungi in the microbial community(Classen et al. 2015; Mucha et al. 2018).A short-term (15 months) soil warming experiment revealed that warming (elevated 1 and 2°C) did not markedly alter the overall soil fungal community structures and α-diversity on the Tibetan Plateau (Xiong et al. 2014). However, other studies have shown that prolonged and sustained warming can cause fungal species and populations to decline. (DeAngelis et al. 2015; Liang et al. 2015). Most studies have shown that different fertilization treatments lead to changes in microbial community structure. The results of Wang et al.(2018) showed that the effects of increased nitrogen fertilization on fungal diversity in forest and desert/shrubland ecosystems were inconsistent with the findings in farmland ecosystems. Fungal diversity in forest and desert/shrubland ecosystems decreased with increasing N application; fungal diversity in farmland decreased with increasing N application. Soil microbial community diversity significantly increased by organic fertilizer application (Gu et al. 2019). Application of phosphorus fertilizer to the soil significantly reduced the abundance of fungal communities in alpine meadows thereby altering the fungal community structure (He et al. 2016). These research results show that the response of soil fugal communities respond to nighttime warming and fertilization application is complex.

To date, most studies on the effects of climate warming on soil fungal communities have been conducted in forest, alpine, and grassland soils (Zhang et al. 2014; Kim et al. 2015; Solly et al. 2017; Cao et al. 2020), and the main method of fertilization has been nitrogen fertilizer, which limits our ability to understand the structure of soil fungal communities in farmland ecosystems change pattern of soil fungal communities in farmland ecosystems. A stable fungal community composition plays an important role in the soil biochemical cycle, maintaining plant health and stabilizing ecosystems (Sun et al. 2017). Thus, investigating soil fungal communities is important. In this study, the objectives were to :1) identify how the soil physical and chemical properties shift in response to nighttime warming and different fertilization regimes; 2) exploring the changing patterns of soil fungal communities affected by nighttime warming and different fertilization measures; and 3) exploring the main factors that influence the structure of fungal communities. This experiment aims to provide a theoretical basis for scientific fertilization practices and sustainable agricultural development.

Materials and Methods

2.1 Site description

The winter wheat pot experimental field was located at the Baima Experimental Station of Nanjing Agricultural University in Nanjing, Jiangsu Province (31°37′N, 119°09′E), from October 2019 to June 2021. The climate of the site is humid subtropical monsoon, with an average annual rainfall of 1147 mm. The annual average temperature is 16.0°C, and the maximum and minimun temperatures are 41.6°C and -14.8°C respectively. The physical and chemical properties of the soil before planting are shown in Table 1.

2.2 Experimental design and soil sampling

The winter wheat variety used in this experiment was Yangmai 16, and sixteen treatments were replicated four times for a total of 64 pots. (1) Two different soils were used, one from Xuchang city (XC, alkaline soil with high nutrient content) and another from Baima town (BM, acidic soil with low nutrient content). (2) Two temperature treatments were designed, a nighttime warming (NW, warming time was 18:00-06:00) and an ambient (AMB) treatment. The heating source was an electric heating tube with infrared radiation. During the whole growth period of wheat, the height was continuously adjusted to keep the distance between the heating device and the crop canopy at 1.5 m (Fig 1). Empty stands without heating pipes were erected in the control area to offset the possible shading effects. The soil temperature increased by approximately 1 ℃. (3) Four types of fertilizer application measures are set(CK: with no fertilizer added), application of mineral nitrogen fertilizers (N: 225 kg N $ha^{-1}yr^{-1}$), application of mineral nitrogen, phosphorus and potassium fertilizers (NPK: 225 kg N $ha^{-1}yr^{-1}$, 170 kg P_2O_5 $ha^{-1}yr^{-1}$ and 170 kg K_2O $ha^{-1}yr^{-1}$), NPK combined with organic fertilizer (M) (NPKM: 225 kg N $ha^{-1}yr^{-1}$, 170 kg P_2O_5 $ha^{-1}yr^{-1}$, 170 kg K_2O $ha^{-1}yr^{-1}$ and 12.5 g M per pot). The nitrogen fertilizer was urea, which was applied twice at a basal dressing to topdressing ratio of 1:1. Additional fertilizer before the wheat pulling stage. Phosphorus and potassium fertilizers were calcium superphosphate and potassium chloride, respectively, and organic fertilizer was organic compound fertilizer, in which the ratio of N:P:K content was 3:1:2, which were all applied before sowing. The size of the plastic bucket used in this experiment was 27 cm in diameter and 24 cm in height. A total of 7.5 kg of soil was packed into each pot. In each pot, 12 wheat seeds were evenly sown, setting seedlings to 8 plants at the wheat trefoil stage.

2.3 Sample collection and physicochemical analysis

Soil samples at a depth of 0-20 cm were collected on April 6th and May 23rd, 2021, respectively. One portion of the soil samples was sieved (2 mm) to remove the plant materials, and roots and stored in a 4℃ refrigerator for soil physicochemical property analysis, and others were stored at -70℃ for DNA extraction and analysis of sequencing data.

A temperature recorder (ZDR-41, Hangzhou Zeda Instrument Co., Ltd., HuangZhou, China) was used to automatically monitor the 5 cm underground soil of winter wheat in the whole growing period. The recorder automatically recorded and saved the temperature data every 30 minutes. The pH was measured using a pH meter, at a soil: water ratio of 1:5. Soil moisture content was determined by drying the soil at 105 ℃ for 12 h. Ammonium nitrogen was determined by the indophenol blue colorimetric method, and nitrate nitrogen was analysed via ultraviolet spectrophotometry. Soil total nitrogen (TN) was determined by the Kjeldahl method. Soil organic matter (SOM) was measured by the external heating method with potassium dichromate ($K_2Cr_2O_7$). Available phosphorus (AP) was determined by sodium bicarbonate–ultraviolet spectrophotometry. Soil available potassium (AK) was measured using flame atomic absorption spectrophotometry.

2.4 DNA extraction and analysis of sequencing data

According to the manufacturer's protocols, total DNA of soil microorganisms was extracted from 0.5 g soil of each subsample with a PowerSoil kit (MoBio Laboratories Carlsbad, CA, USA). PCR amplification of the V3-V4 hypervariable region fragment of the 18S rRNA gene was performed using ITS1 (ITS1 5’-CTTGGTCATTTAGAGGAAGTAA-3’) and ITS2 (ITS2 5’-GCTGCGTTCTTCATCGATGC-3’) as sequencing primers to purify the DNA sequence (Yu et al., 2019). The thermocycling conditions were as follows: predenaturation at 95 °C for 2 min, denaturation at 95 °C for 30 s, annealing at 55 °C for 30 s, extension at 72 °C for 30 s, 25 cycles, and extension at 72°C for 5 min. Each sample had 3 replicates. The PCR products of the same sample were mixed and detected by 2% agarose gel electrophoresis. The PCR products were cut and recovered by using the AxiPrepDNA gel recovery kit (AXYGEN Company) and eluted by Tris HCl and 2% agarose electrophoresis. With reference to the preliminary quantitative results of electrophoresis, the PCR products were detected and quantified with the QuantiFluorTM-ST blue fluorescence quantitative system (Promega), and the corresponding proportions were mixed according to the sequencing quantity requirements of each sample. The fungi were sequenced on the Illumina MiSeqPE250 platform of Shanghai Meiji Biomedical Technology Co., Ltd.

2.5 Statistical Analysis

Process all sequencing data on the Majorbio Cloud Platform (http://www.majorbio.com, accessed on 3 May 2020). Mothur software (version 1.31.2, http://www.mothur.org/) was used to analyse the α diversity index of fungi (including Shannon, Simpson, Chao1 and ACE) (Schoch et al. 2012). A bubble map (correlation) between soil properties and fungal alpha diversity was constructed using the “corrplot” package in R software. Two-way analysis of variance (ANOVA) was applied to evaluate the effects of nighttime warming, different fertilization treatments, and their interaction on the diversity of soil fungi. The data presented in this paper are the average of three repetitions. The underlying data were analyzed using SPSS software, version 16.

Results

3.1 Soil physicochemical properties

Tables 2 and 3 show the changes in soil physicochemical properties as a result of nighttime warming and different fertilization practices. Among these two soils, the NW and fertilization treatments had lower pH values than the CK treatment regardless of the fertilizer regime, and the effect of warming was more obvious ($P<0.01$). In XC soil, the soil AK ($P<0.01$) and AP contents considerably decreased in the NW treatment, while fertilizer application eased this downwards trend to a certain extent, especially in NPKM-treated soils. The contents of three different forms of nitrogen showed different response trends under NW and different fertilization regimes. NW increased the content of soil NH_4^+-N and TN but decreased the content of NO_3^--N. Fertilizer addition resulted in a significant increase in soil NH_4^+-N, NO_3^--N and TN ($P<0.01$) compared with the CK group. In BM soil, the change trend of soil nutrients was roughly the same as that in XC soil. Compared with CK, NW led to higher soil NH_4^+-N and TN, which increased TN by 32.3% on average and reduced the contents of soil AK, AP and NO_3^--N. NW had no significant effect on SOM content in soil. Fertilization increased the contents of soil NO_3^--N, NH_4^+-N and TN, which showed NPKM>NPK>N>CK treatment as a whole.

Variance analysis showed that NW had a significant impact on other environmental factors except AP. All environmental factors were significantly affected by fertilization. Nighttime warming and fertilization had an interactive effect on soil TN, AP and AK.

The variance analysis showed that NW had a significant impact on all environmental factors except soil organic matter. Fertilization had a significant impact on all environmental factors. NW and fertilization had an interactive effect on soil TN,

NH_4^+-N, NO_3^--N, AP and AK.

3.2 Soil fungal community composition

Warming and fertilization did not significantly change the dominant phylum of soil fungi (Figs. 3,4). *Ascomycota* dominated across treatments, with relative abundances ranging from 34.84% to 67.48%, followed by *Mortierellomycota* (12.66% - 33.81%), *Basidiomycota* (1.92% - 13.65%) and *Olpidiomycota* (0.2% - 18.26%). However, the relative abundances changed. The highest abundance in both soils was in the phylum *Ascomycota*. Overall, NW increased the relative abundance of *Ascomycota* but decreased that of *Basidiomycota* under the same fertilization application level in the two soils. However, under the treatment of nitrogen fertilizer alone, NW reduced the abundance of *Ascomycetes* and increased the abundance of *Basidiomycetes*.

At the genus level (Figs. 5,6), among these two soils, night-time warming decreased the relative abundance of *Mortierella* but increased it in fertilized treatments in both soils as a whole. Nighttime warming also increased the relative abundance of *Fusarium*. Compared with CK, fertilization reduced the relative abundance of *Fusarium* in BM soil, especially under the NPKM treatment.

3.3 Analysis of igh-Quality sequences

In XC soil, the alpha diversity index results of the fungal community showed that NW generally increased the Ace (797.4) and Chao (803.6) indices by an average of 2.13% and 1.54%, respectively. Different fertilization regimes had the same effect on richness, and the influence trend was NPKM>N>NPK>CK under the two temperature treatments. Among them, the increase effect of NPKM treatment was the most obvious, which increased the Ace index by 19.2% and 23.6% and the Chao index by 23.3% and 24.3%, respectively. Nighttime warming and fertilization also significantly changed the richness of fungi in BM soil (Table 5). NW increased the Ace (537.1) and Chao (534.1) indices of BM soil by an average of 10.0% and 5.81%, respectively. The Ace index and Chao index of the CK treatment were obviously lower than those of all fertilization treatments, which was consistent with the results of the XC soil. Additionally, the Shannon index of the NW treatment was significantly higher than that of the AMB treatment, while the Simpson index was lower than that of the AMB treatment in the two soils. These results indicate that NW increased the diversity of soil fungal communities.

The variance analysis showed that fertilization had a significant effect on the richness and Simpson index of soil fungi in XC soil. NW had a significant effect on the diversity index but had a slight effect on the richness, and the interaction between temperature and fertilization had little effect on the richness of soil fungi. Temperature, fertilization, and the interaction between temperature and fertilization had a significant impact on the richness and Simpson index of soil fungi in BM soil, especially fertilization, which had the greatest impact on richness.

3.4 Correlation analysis between soil fungal community diversity and environmental factors

For the XC soil (Fig. 7), there was a positive correlation among ST, AK, AP, NH_4^+-N, SOM and soil fungal community diversity, while SM (soil moisture) and pH were negatively correlated with it. Soil AP and SOM had the greatest influence on the richness of soil fungal communities in winter wheat ($P>0.01$). For the BM soil (Fig.

8), ST, SM, pH and AK were the key factors affecting the change in soil fungal alpha diversity in BM. ST, AK, AP, SOM and soil fungal alpha diversity were positively correlated. At the same time, soil pH and SM were negatively correlated with soil fungal alpha diversity in both soils, which indicated that decreasing soil moisture and soil pH properly can increase the diversity and richness of soil fungi.

3.5 The effects of soil physical and chemical properties on fungal diversity

To further explore the direct and indirect effects of night-time warming and fertilization on soil fungal communities, we synthesized the experimental data of XC and BM soils and used AMOS software to build a structural equation model to verify our hypothesis. Soil temperature (β=0.368, standardized coefficient) can directly affect the diversity of soil fungal communities (Fig. 9), and it can also indirectly affect fungal communities by affecting SM, pH, SOM and the soil carbon-nitrogen ratio (C/N). Among them, the correlations between soil temperature and soil moisture (β=-0.589, standardized coefficient) and C/N (β=-0.229, standardized coefficient) were the strongest. The ST and SOM (β=0.078, standardized coefficient) reached a significant level with the diversity of oil fungal communities.

Discussion

4.1 Effects of night-time warming and different fertilization regimes on soil physicochemical factors

Our research showed that night-time warming reduced soil pH to a certain extent, which was similar to the results of Guo et al (2021). Organic fertilizer application reduced the pH value of alkaline soil while alleviating the decrease in pH in acidic soil, which was consistent with the research results of Wei et al (2017). This discrepancy may be attributed to the application of organic fertilizer increasing the content of soil organic carbon, and organic carbon is an acid-base buffer that can neutralize the acidity and alkalinity of soil and make the soil tend to be neutral (Wang et al. 2016). Studies have shown that warming promotes the wheat root activity, which is beneficial to the nitrogen uptake from soil (Purakayastha et al. 2019). In this study, the NH_4^+-N content of the soil after warming treatment was significantly higher than that of CK, which may be because the temperature rise in a certain range enhanced the nitrogen conversion and ammonification, and facilitated the conversion of amino acids to NH_4^+-N (Guo et al. 2015). However, in alkaline soil, NH_4^+-N in the surface layer was easily volatilized in the form of NH_3 molecules (Beier et al. 2004; Xu et al. 2021), and we observed that the NH_4^+-N content in XC soil was slightly lower than that in BM soil. Fertilization could increase the concentration of available nitrogen in soil . In this study, different forms of nitrogen contents increased to different degrees under the fertilization treatment. It was found that AP, AK and SOM levels in the soil were increased to varying degrees by the application of organic fertilizers. (Bei et al. 2018; Lu et al. 2021). The results of this study are similar to its.

4.2 Effects of nighttime warming and different fertilization regimes on soil fungal community

In this study, *Ascomycota*, *Mortierellomycota*, *Basidiomycota*, and *Olpidiomycota* were the dominant fungal phyla in the two different soil types, accounting for more than 80% of the total fungal phyla. Similar results have been observed in other studies (Pan et al. 2020; Yao et al. 2021; Wang et al. 2022). This result showed that the strong adaptations of these species to the wheat soil environment. *Ascomycota* grow rapidly and are capable of breaking down substances in the soil that are difficult to break down, such as lignin and keratin. It is the main driver of nutrient cycling and energy flow (Beimforde et al. 2014). It is also the main decomposer in agricultural soils (Ma et al. 2013), and the addition of organic fertilizer is beneficial to its growth (Wang et al. 2018). Overall, NW increased the relative abundance of *Ascomycota* in the two soils. However, under the treatment of nitrogen fertilizer alone, NW reduced the abundance of *Ascomycota*. *Fusarium* is a fungal pathogen that causes great harm to the roots of crops such as wheat and corn (Fernandez et al. 2005; Liu et al. 2015; Tagele et al. 2019). In this experiment, the abundance of *Fusarium* increased under the night-time warming treatment, but in the combination treatment of organic fertilizer and inorganic fertilizer, its abundance was lower than that of the control and chemical fertilizer treatments, which indicated that the organic fertilizer application could reduce the risk of diseases caused by *Fusarium* in winter wheat. This conclusion was also obtained by Wen et al (2020).

Our study showed that fungal community compositions were significantly altered after night-time warming and different fertilizer applications. However, it was found that short-term warming treatments in alpine peatlands did not result in significant changes in the α diversity of fungal communities. (Wang et al. 2022). DeAngelis et al (DeAngelis et al. 2015) demonstrated that long-term experimental warming often leads to a decrease in soil fungal abundance. Wen et al (2020) found that organic fertilizer significantly changed the α diversity of soil fungi, while chemical fertilizer did not. Xiang et al (2020) reported that the abundance and diversity of fungi increased with the application of organic fertilizer and NPK, and long-term fertilization led to great changes in the composition of fungal communities. In this experiment, our results showed that both warming and fertilization could increase the diversity and richness index of soil fungal communities in the two soils, in which temperature was the predominant factor influencing the diversity of soil fungi, and the richness was mainly related to fertilization. The differences may be caused by a variety of factors, such as differences in temperature increase range, soil types, research methods and research duration (Leon-Sanchez et al. 2018).

4.3 Environmental factors affecting soil fungal community structure under nighttime warming and fertilization.

Pearson correlation analysis found that ST, AK, SOM and AP had significant relationships with the composition of the XC and BM fungal communities. Soil organic carbon and AK, and AP contents have ever been reported as important factors influencing the fungal community (Cai et al. 2021). Ma et al (2018) also found that organic matter was an important factor in the change in fungal community composition. It may be that most fungi are heterotrophs and their growth is dependent on external carbon sources, so unstable organic matter has profound influences on their abundance (Broeckling et al. 2008). By analyzing the structural equation model we found that increased soil temperature affects organic matter and carbon to nitrogen ratios, which indirectly leads to changes in soil fungal community structure. The SEM further explained that the soil organic matter addition significantly increased the diversity of soil fungal communities. Liu et al (Liu et al. 2022) also showed that there was an obvious positive correlation between organic matter and the diversity of soil fungi in the effects of warming on wheat soil fungi experiments. Proper increases in soil temperature and soil environments rich in organic matter may be beneficial to improve the diversity of fungal communities.

Conclusions

Two years of night-time warming and different fertilization regimes had a significant impact on soil physicochemical properties, soil fungal species composition, richness and diversity in winter wheat. Both night-time warming and fertilization, especially the addition of organic fertilizer, significantly increased the richness and diversity of soil fungal communities compared to CK. The SEM further revealed that ST and SOM play an important role in shaping the structure of fungal communities. Furthermore, the addition of organic fertilizer can reduce the relative abundance of Fusarium. Thus, the incidence of winter wheat root rot may be reduced.

Credit authorship contribution statement

Ning Han: Writing – original draft, Formal analysis, Writing – review & editing. **Chaoran Yang:** Formal analysis. **Mengting Liu:** Visualization. **Xinyu Pei:** Formal analysis. **Ruilin Mao:** Supervision. **Changqing Chen:** Conceptualization, Methodology, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was supported by the Special Fund for Agro-scientific Research in the Public Interest (201503122), The Central Public Interest Scientific Institution Basal Research Fund of Institute of Crop Science (Y2016PT12), and the Innovation Program of CAAS (Y2016XT01).

References

1. Ye Z, Qiu X L, Chen J, Cammarano D, Ge ZL, C. Ruane A, Liu LL, Tang L, Cao WX, Liu B and Zhu Y. 2020. Impacts of 1.5 degrees C and 2.0 degrees C global warming above pre-industrial on potential winter wheat production of China[J]. Eur J Agron, 120. https://doi.org/10.1016/j.eja.2020.126149
2. Yan X, Wang K, Song L, Wang X, Wu D. 2017. Daytime warming has stronger negative effects on soil nematodes than night-time warming[J]. Sci Rep-uk, 7(1): 1-6. https://doi.org/10.1038/srep46881
3. Li J, Ma L, Li R, et al. Impacts of nighttime warming on rice growth, physiological properties and yield under water saving irrigation[J]. Int J Global Warm, 2020, 21(2):105. https://doi.org/10.1504/IJGW.2020.108182
4. Richard D, Igor E, Alexander C, Stephen O, Sergej Z. 2017. Davy R, Esau I, Chernokulsky A, et al. Diurnal asymmetry to the observed global warming[J]. Int J Climatol, 2017, 37(1): 79-93. https://doi.org/10.1002/joc.4688
5. Rossi S, Isabel N. 2017. Bud break responds more strongly to daytime than night-time temperature under asymmetric experimental warming[J]. Global Change Biol, 23(1): 446-454. https://doi.org/10.1111/gcb.13360
6. Francioli D, Schulz E, Lentendu G, et al. Mineral vs. Organic Amendments: Microbial Community Structure, Activity and Abundance of Agriculturally Relevant Microbes Are Driven by Long-Term Fertilization Strategies[J]. Front Microbiol, 2016,7: 1446. https://doi.org/10.3389/fmicb.2016.01446
7. Zhang Q, Zhou W, Liang G, et al. Effects of different organic manures on the biochemical and microbial characteristics of albic paddy soil in a short-term experiment[J]. Plos One, 2015, 10(4): e0124096. https://doi.org/10.1371/journal.pone.0124096
8. Huang J , Rozelle S , Zhu X , et al. Agricultural and rural development in China during the past four decades: an introduction[J]. Aust J Agr Resour Ec, 2020, 64(1): 1-13. https://doi.org/10.1111/1467-8489.12352
9. Guo Y Z, Wang J Y. Spatiotemporal changes of chemical fertilizer application and its environmental risks in China from 2000 to 2019[J]. Int J Env Res Pub He, 2021, 18(22). https://doi.org/10.3390/ijerph182211911
10. Gu S S; Hu Q L; Cheng, Y Q et al. Application of organic fertilizer improves microbial community diversity and alters microbial network structure in tea (Camellia sinensis) plantation soils[J]. Soil Till Res, 2019,195(C). https://doi.org/10.1016/j.still.2019.104356

11. Campbell B J, Polson S W, Hanson T E, et al. The effect of nutrient deposition on bacterial communities in Arctic tundra soil[J]. Environ Microbiol, 2010, 12(7): 1842-1854. https://doi.org/10.1111/j.1462-2920.2010.02189.x
12. Miao C P, Mi Q L, Qiao X G, et al. Rhizospheric fungi of Panax notoginseng: Diversity and antagonism to host phytopathogens[J]. J Ginseng Res, 2016, 40(2): 127-134. https://doi.org/10.1016/j.jgr.2015.06.004
13. Tedersoo, L.; Bahram, M.; Põlme, S et al. A Global diversity and geography of soil fungi[J]. Science, 2014, 346: 1256688. https://doi.org/10.1016/j.jgr.2015.06.004
14. Chen J, Arafat Y, Ud Din I et al. Nitrogen fertilizer amendment alter the bacterial community structure in the rhizosphere of rice (Oryza sativa L.) and improve crop yield[J]. Front Microbiol, 2019, 10:2623-2623. https://doi.org/10.3389/fmicb.2019.02623
15. Frąc M, Hannula S E, Bełka M, et al. Fungal biodiversity and their role in soil health[J]. Front Microbiol, 2018, 9: 707. https://doi.org/10.3389/fmicb.2018.00707
16. Mateos-Rivera A, Yde J C, Wilson B, et al. The effect of temperature change on the microbial diversity and community structure along the chronosequence of the sub-arctic glacier forefield of Styggedalsbreen (Norway)[J]. Fems Microbiol Ecol, 2016, 92(4): fnw038. https://doi.org/10.1093/femsec/fiw038
17. Liu J, Sui Y, Yu Z, et al. Soil carbon content drives the biogeographical distribution of fungal communities in the black soil zone of northeast China[J]. Soil Biol Biochem, 2015, 83: 29-39. https://doi.org/10.1016/j.soilbio.2015.01.009
18. Watson T T, Nelson L M, Neilsen D, et al. Soil amendments influence Pratylenchus penetrans populations, beneficial rhizosphere microorganisms, and growth of newly planted sweet cherry[J]. Appl Soil Ecol, 2017, 117-118: 212-220. https://doi.org/10.1016/j.apsoil.2017.04.014
19. Pan H, Chen M, Feng H, et al. Organic and inorganic fertilizers respectively drive bacterial and fungal community compositions in a fluvo-aquic soil in northern China[J]. Soil Till Res, 2020, 198: 104540. https://doi.org/10.1016/j.still.2019.104540
20. Mucha J, Peay K G, Smith D P, et al. Effect of simulated climate warming on the ectomycorrhizal fungal community of boreal and temperate host species growing near their shared ecotonal range limits[J]. Microb Ecol, 2018, 75(2): 348-363. https://doi.org/10.1007/s00248-017-1044-5
21. Song Y Y, Song C C, Hou A X, et al. Effects of temperature and root additions on soil carbon and nitrogen mineralization in a predominantly permafrost peatland[J]. CATENA, 2018, 165: 381-389. https://doi.org/10.1016/j.catena.2018.02.026

22. Classen A T, Sundqvist M K, Henning J A, et al. Direct and indirect effects of climate change on soil microbial and soil microbial-plant interactions: What lies ahead?[J]. Ecosphere, 2015, 6(8): 1-21. https://doi.org/10.1890/ES15-00217.1
23. Xiong J, Chu H, Sun H, et al. Divergent responses of soil fungi functional groups to short-term warming[J]. Microb Ecol, 2014, 68(4): 708-715. https://doi.org/10.1007/s00248-014-0385-6
24. DeAngelis K M, Pold G, Topcuoglu B D, et al. Long-term forest soil warming alters microbial communities in temperate forest soils[J]. Front Microbiol, 2015, 6: 104. https://doi.org/10.3389/fmicb.2015.00104
25. Liang C, Gutknecht J L M, Balser T C. Microbial lipid and amino sugar responses to long-term simulated global environmental changes in a California annual grassland[J]. Front Microbiol, 2015, 6: 385. https://doi.org/10.3389/fmicb.2015.00335
26. Wang C, Liu D, Bai E. Decreasing soil microbial diversity is associated with decreasing microbial biomass under nitrogen addition[J]. Soil Biol Biochem, 2018, 120: 126-133. https://doi.org/10.1016/j.soilbio.2018.02.003
27. He D, Xiang X, He J S, et al. Composition of the soil fungal community is more sensitive to phosphorus than nitrogen addition in the alpine meadow on the Qinghai-Tibetan Plateau[J]. Biol Fert Soils, 2016, 52(8): 1059-1072. https://doi.org/10.1007/s00374-016-1142-4
28. Zhang B, Chen S, He X, et al. Responses of soil microbial communities to experimental warming in alpine grasslands on the Qinghai-Tibet Plateau[J]. Plos One, 2014, 9(8): e103859. https://doi.org/10.1111/ejss.12240
29. Kim Y C, Gao C, Zheng Y, et al. Arbuscular mycorrhizal fungal community response to warming and nitrogen addition in a semiarid steppe ecosystem[J]. Mycorrhiza, 2015, 25(4): 267-276. https://doi.org/10.1007/s00572-014-0608-1
30. Solly E F, Lindahl B D, Dawes M A, et al. Experimental soil warming shifts the fungal community composition at the alpine treeline[J]. New Phytol, 2017, 215(2): 766-778. https://doi.org/10.1111/nph.14603
31. Cao J L, Lin T C, Yang Z J, et al. Warming exerts a stronger effect than nitrogen addition on the soil arbuscular mycorrhizal fungal community in a young subtropical Cunninghamia lanceolata plantation[J]. Geoderma, 2020, 367: 114273. https://doi.org/10.1016/j.geoderma.2020.114273
32. Sun Q, Liu Y, Yuan H, et al. The effect of environmental contamination on the community structure and fructification of ectomycorrhizal fungi[J]. Microbiologyopen, 2017, 6(1): e00396. https://doi.org/10.1002/mbo3.396

33. Schoch C L, Seifert K A, Huhndorf S, et al. Nuclear ribosomal internal transcribed spacer (ITS) region as a universal DNA barcode marker for Fungi[J]. P Natl Acad Sci USA, 2012, 109(16): 6241-6246. https://doi.org/10.1073/pnas.1117018109
34. Yu C, Han F, Fu G. Effects of 7 years experimental warming on soil bacterial and fungal community structure in the Northern Tibet alpine meadow at three elevations[J]. Sci Total Environ, 2019, 655: 814-822. https://doi.org/10.1016/j.scitotenv.2018.11.309
35. Guo W Q, Xu X X, Lu L, et al. Effects of Warming and Biochar Addition on Soil Nutrients and Microbial Biomass in Wheat Fields[J]. J. Ecol. Rural Environ., 2021, 37(5): 611-618. https://doi.org/10.19741/j.issn.1673-4831.2020.0794
36. Wei M, Hu G, Wang H, et al. 35 years of manure and chemical fertilizer application alters soil microbial community composition in a Fluvo-aquic soil in Northern China[J]. Eur J Soil Biol, 2017, 82: 27-34. https://doi.org/10.1016/j.ejsobi.2017.08.002
37. Wang A H, D Z Q, T Y et al. Effects of different fertilizations on acidification of a greenhouse alkaline soil[J]. Soils, 2016, 48(2): 349-354. https://doi.org/10.13758/j.cnki.tr.2016.02.021
38. Purakayastha T J, Bera T, Bhaduri D, et al. A review on biochar modulated soil condition improvements and nutrient dynamics concerning crop yields: Pathways to climate change mitigation and global food security[J]. Chemosphere, 2019, 227: 345-365. https://doi.org/10.1016/j.chemosphere.2019.03.170
39. GUO H, DE K, LU G, et al. The impacts of simulative warming and adding nitrogen on the grassland productivity of alpine meadow[J]. Acta Agrestia Sin, 2015, 23(2): 322. https://doi.org/10.11733/j.issn.1007-0435.2015.02.016
40. Beier C, Emmett B, Gundersen P, et al. Novel approaches to study climate change effects on terrestrial ecosystems in the field: Drought and passive nighttime warming[J]. Ecosystems, 2004, 7(6): 583-597. https://doi.org/10.1007/s10021-004-0178-8
41. Xu X R, Ouyang X, Gu Y N, et al. Climate change may interact with nitrogen fertilizer management leading to different ammonia loss in China's croplands[J]. Global Change Biol, 2021, 27(24): 6525-6535. https://doi.org/10.1111/gcb.15874
42. Bei S, Zhang Y, Li T, et al. Response of the soil microbial community to different fertilizer inputs in a wheat-maize rotation on a calcareous soil[J]. Agr Ecosyst Environ, 2018, 260: 58-69. https://doi.org/10.1016/j.agee.2018.03.014
43. Lu W D, Li J H, Luo T, et al. Effects of different organic fertilizer replacement rates on wheat yield and soil nutrients over three consecutive years[J]. Plant Nutr. Fert. Sci., 2021, 27(08): 1330-1338. https://doi.org/10.11674/zwyf.2021073

44. Pan H, Chen M, Feng H, et al. Organic and inorganic fertilizers respectively drive bacterial and fungal community compositions in a fluvo-aquic soil in northern China[J]. Soil Till Res, 2020, 198: 104540. https://doi.org/10.1016/j.still.2019.104540
45. Yao S T, Lu G G, Deng Y, et al. Effects of simulated warming on soil fungal community composition and diversity[J]. Ecology and Environmental Sciences, 2021, 30(7): 1404-1411.3. https://doi.org/ 10.16258/j.cnki.1674-5906.2021.07.009
46. Wang X, Li Y, Yan Z, et al. The divergent vertical pattern and assembly of soil bacterial and fungal communities in response to short-term warming in an alpine peatland[J]. Front Plant Sci, 2022, 13: 986034. https://doi.org/10.3389/fpls.2022.986034
47. Beimforde C, Feldberg K, Nylinder S, et al. Estimating the Phanerozoic history of the Ascomycota lineages: combining fossil and molecular data[J]. Mol Phylogenet Evol, 2014, 78: 386-398. https://doi.org/10.1016/j.ympev.2014.04.024
48. Ma A, Zhuang X, Wu J, et al. Ascomycota members dominate fungal communities during straw residue decomposition in arable soil[J].Plos One, 2013, 8(6): e66146. https://doi.org/10.1371/journal.pone.0066146
49. Fernandez M R，Zentner R P. The impact of crop rotation and N fertilizer on common root rot of spring wheat in the brown soil zone of western Canada[J]. Can J Plant Sci, 2005, 85(3): 569-575. https://doi.org/10.4141/P04-041
50. Liu C, Ogbonnaya F C, Bürstmayr H. Resistance to Fusarium crown rot in wheat and barley: a review[J]. Plant Breeding, 2015, 134(4): 365-372. https://doi.org/10.1111/pbr.12274
51. Tagele S, Kim S, Lee H, et al. Potential of Novel Sequence Type of Burkholderia cenocepacia for Biological Control of Root Rot of Maize (Zea mays L.) Caused by Fusarium temperatum[J]. Int J Mol Sci, 2019, 20(5). https://doi.org/10.3390/ijms20051005
52. Wang J, Rhodes G, Huang Q, et al. Plant growth stages and fertilization regimes drive soil fungal community compositions in a wheat-rice rotation system [J]. Biol Fert Soils, 2018, 54(6): 731-742. https://doi.org/10.1007/s00374-018-1295-4
53. Wen Y C, Li H Y, Lin Z A, et al. Long-term fertilization alters soil properties and fungal community composition in fluvo-aquic soil of the North China Plain[J]. Sci Rep-uk, 2020, 10(1): 7198. https://doi.org/10.1038/s41598-020-64227-6
54. Xiang X, Liu J, Zhang J, et al. Divergence in fungal abundance and community structure between soils under long-term mineral and organic fertilization[J]. Soil Till Res, 2020, 196. https://doi.org/10.1016/j.still.2019.104491

55. Leon-Sanchez L, Nicolas E, Goberna M, et al. Poor plant performance under simulated climate change is linked to mycorrhizal responses in a semi-arid shrubland[J]. J Ecol, 2018, 106(3): 960-976. https://doi.org/10.1111/1365-2745.12888
56. Cai J, Zhang J, Ding Y, et al. Different Fertilizers Applied Alter Fungal Community Structure in Rhizospheric Soil of Cassava (Manihot esculenta Crantz) and Increase Crop Yield[J]. Front Microbiol, 2021, 12: 663781. https://doi.org/10.3389/fmicb.2021.663781
57. Ma M, Jiang X, Wang Q, et al. Responses of fungal community composition to long-term chemical and organic fertilization strategies in Chinese Mollisols[J]. Microbiologyopen, 2018, 7(5): e00597. https://doi.org/10.1002/mbo3.597
58. Broeckling C D, Broz A K, Bergelson J, et al. Root exudates regulate soil fungal community composition and diversity[J]. Appl Environ Microb, 2008, 74(3): 738-744. https://doi.org/10.1128/AEM.02188-07
59. Liu J, Long Z, Zhang J, et al. Effects of nightly warming and nitrogen application on the diversity of soil fungi in winter wheat in the lower reach of the Yangtze River[J]. Arch Agron Soil Sci, 2022, 68(6): 838-851. https://doi.org/10.1080/03650340.2020.1858477

Fig. 1 System structure of Free Air Temperature Increased (FATI) in winter wheat field.

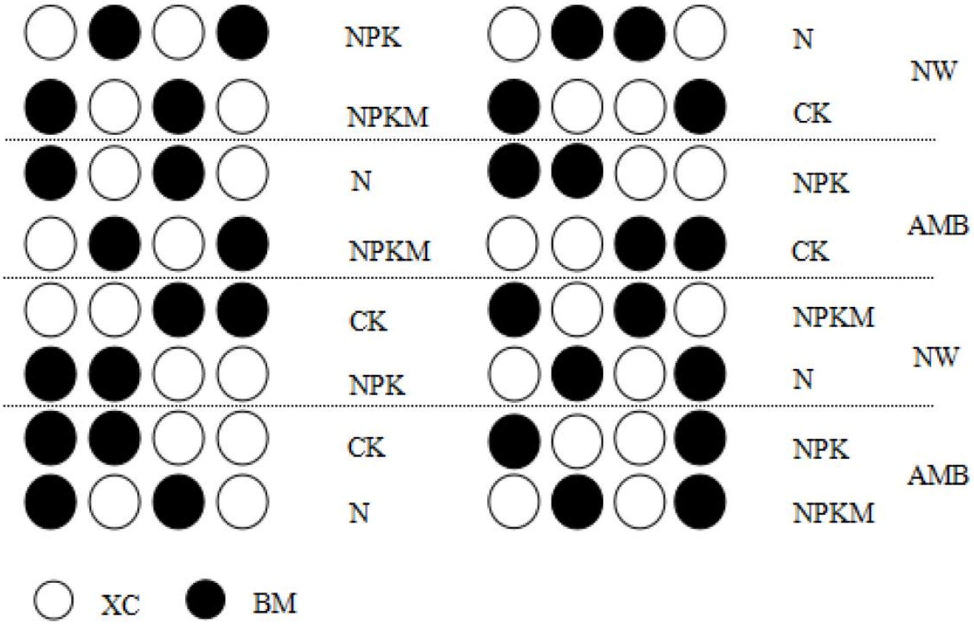


Fig. 2 Experimental plot layout. XC (the soil from Xuchang city); BM (the soil from Baima town); AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of

mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

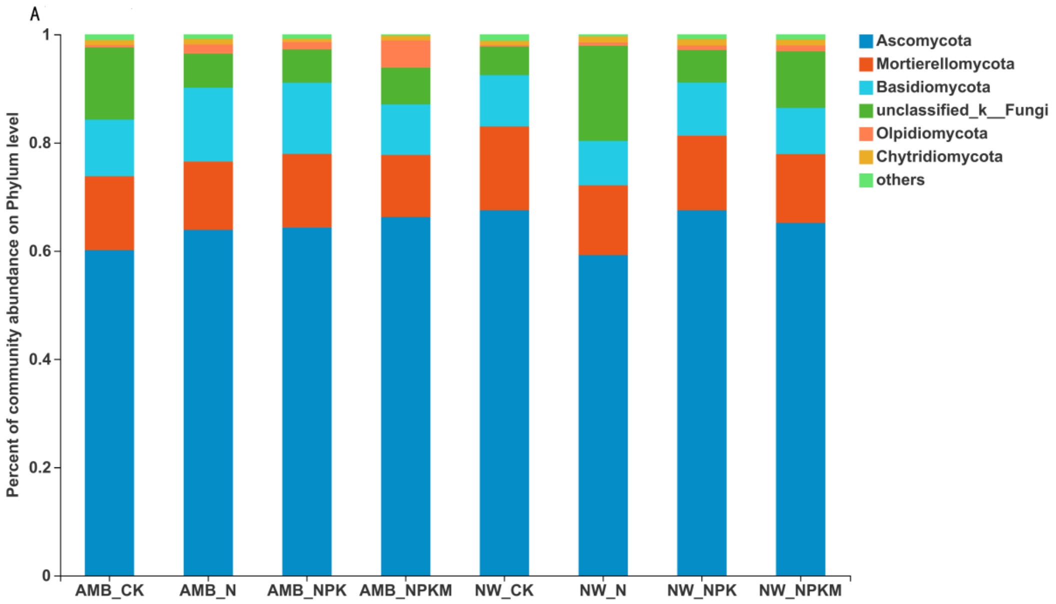


Fig. 3 Effects of night-time warming and different fertilization regimes on the community structure of soil fungi at the phylum level of XC. AMB: ambient, NW: nighttime warming, Percent of community abundance<1% are classified as "Others", the same below. AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

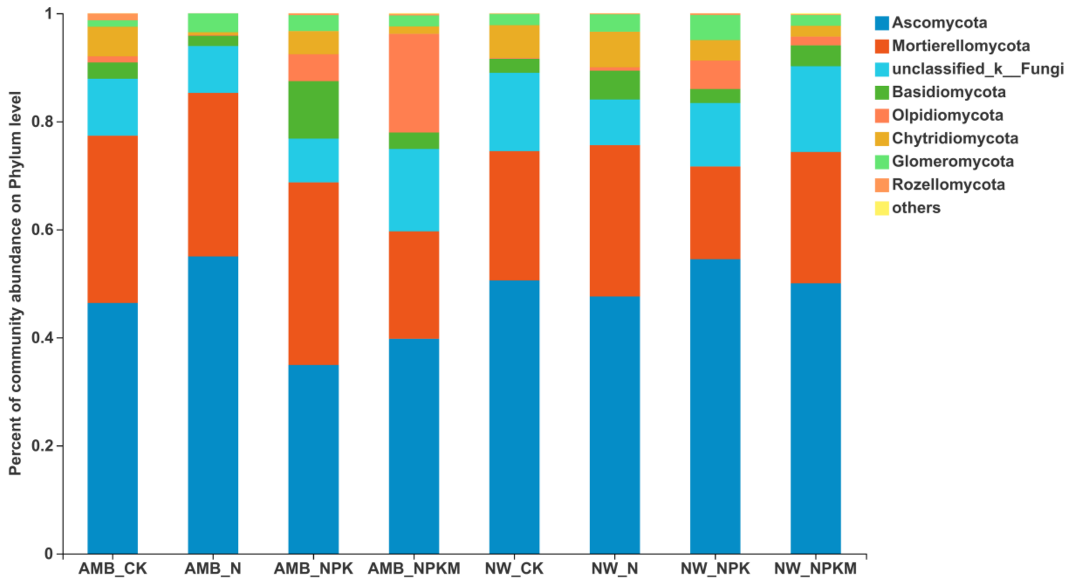


Fig. 4 Effects of night-time warming and different fertilization regimes on the community structure of soil fungi at the phylum level of BM. AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

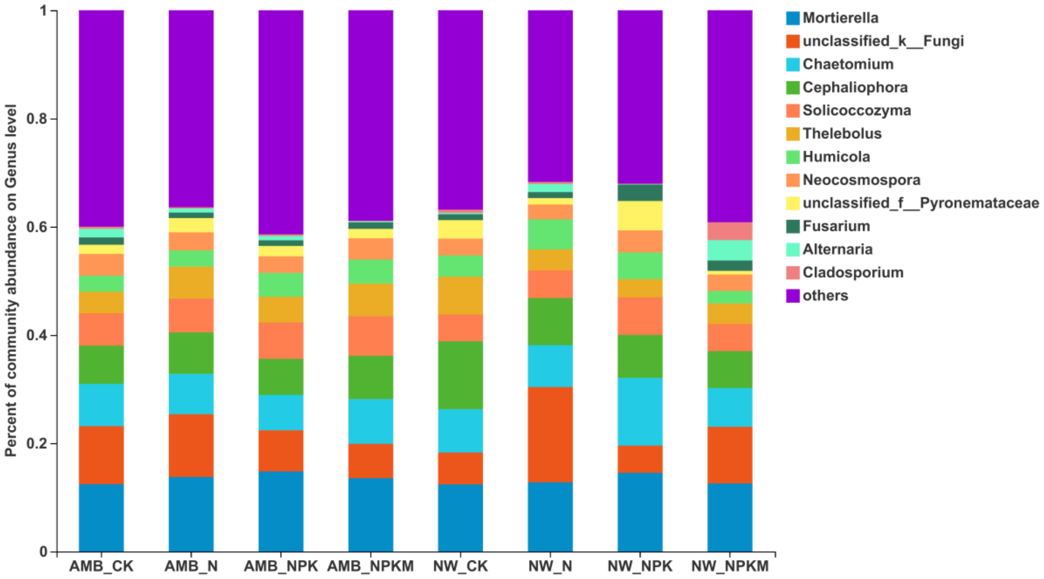


Fig. 5 Effects of night-time warming and different fertilization measures on the community structure of soil fungi at the genus level of XC. AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

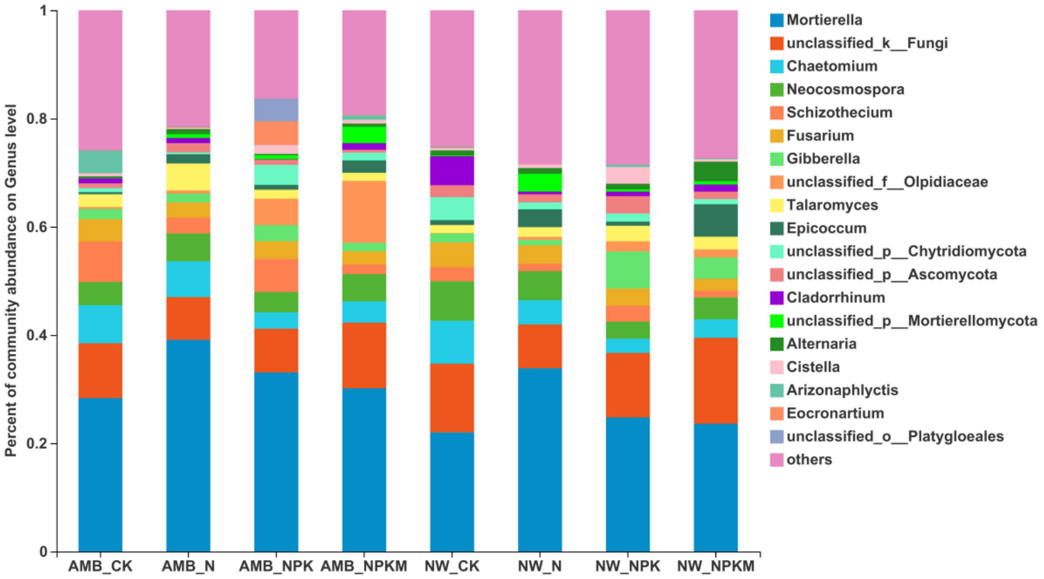


Fig. 6 Effects of night-time warming and different fertilization measures on the community structure of soil fungi at the genus level of BM. AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

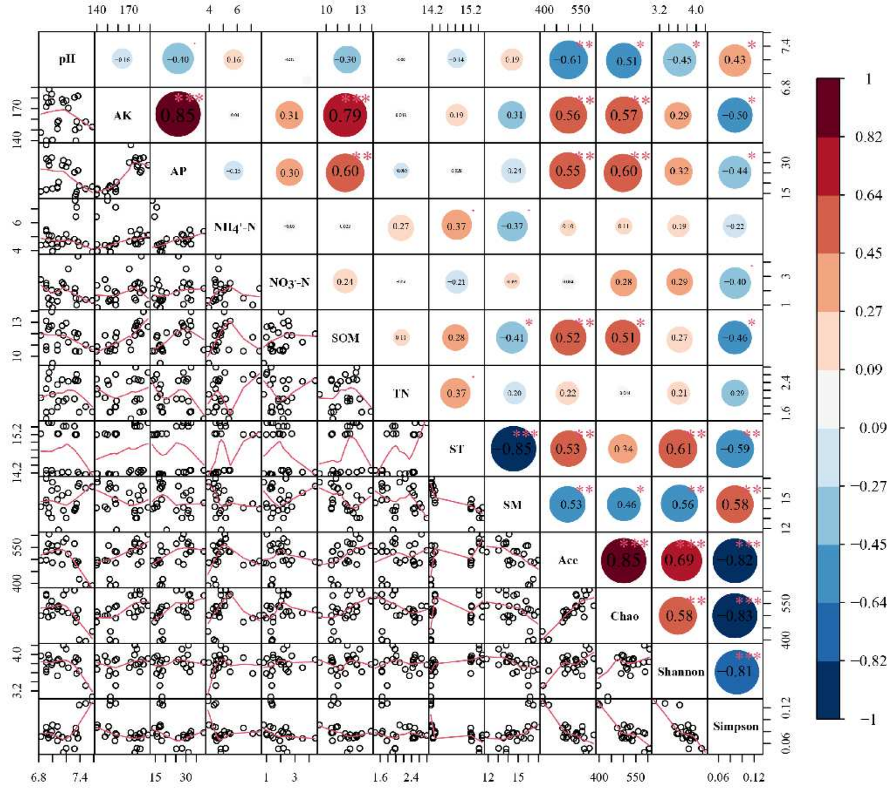


Fig. 7 Pearson correlation analysis showing the relationships between environmental factors and soil fungal community alpha diversity of XC. pH: soil acidity, AK: available potassium, AP: available phosphorus, NH_4^+-N: ammonium nitrogen, NO_3^--N: nitrate nitrogen, SOM: organic matter, TN: total nitrogen, ST: soil temperature, SM: soil moisture, the same as below.

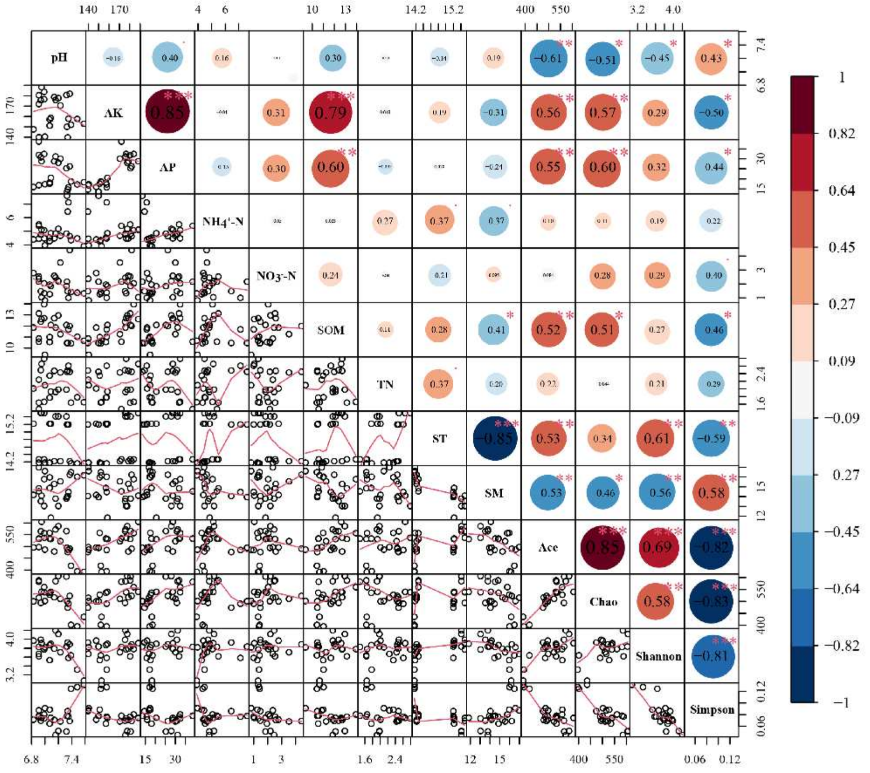
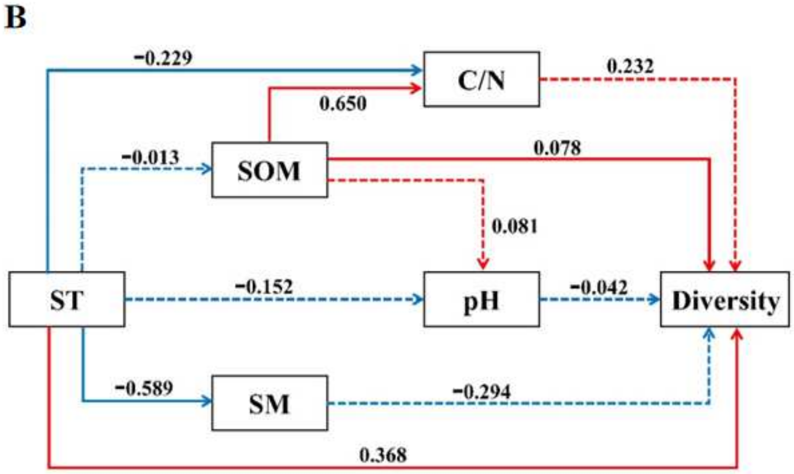


Fig. 8 Pearson correlation analysis showing the relationships between environmental factors and soil fungal community alpha diversity of BM. pH: soil acidity, AK: available potassium, AP: available phosphorus, NH_4^+-N: ammonium nitrogen, NO_3^--N: nitrate nitrogen, SOM: organic matter, TN: total nitrogen, ST: soil temperature, SM: soil moisture, the same as below.



P=0.748; CMIN=1.22; GFI=0.992; AIC=37.22; RMSEA=0.000

Fig. 9 Structural equation models as predictors of soil fungal diversity.

Solid red arrows represent positive paths (P<0.05), solid blue arrows represent negative paths (P<0.05) and dotted grey arrows represent nonsignificant paths (P>0.05). The estimated value of the path coefficient represents the size of the impact scale. ST: soil temperature; SM: soil moisture; pH: soil acidity; SOM: soil organic matter; C/N: soil carbon nitrogen ratio.

Table 1 Basic physical and chemical properties of tested soil

Soil	pH	SOM $g \cdot kg^{-1}$	TN $g \cdot kg^{-1}$	AP $mg \cdot kg^{-1}$	AK $mg \cdot kg^{-1}$
XC	7.40	18.79	3.90	41.81	191.92
BM	6.63	10.70	2.62	23.98	146.24

XC(the soil from Xuchang city); BM(the soil from Baima town); pH: soil acidity; SOM: organic matter; TN: total nitrogen; AP: available phosphorus AK: available potassium.

Table 2. Effects of night-time warming and different fertilization regimes on soil properties of XC

Temperature	Fertilization	pH	AK $mg \cdot kg^{-1}$	AP $mg \cdot kg^{-1}$	NH_4^+-N $mg \cdot kg^{-1}$	NO_3^--N $mg \cdot kg^{-1}$	TN $g \cdot kg^{-1}$	SOM $g \cdot kg^{-1}$
AMB	CK	7.95±0.08a	182.13±2.56c	30.29±0.87c	2.92±0.19b	14.93±0.30c	3.47±0.05c	18.64±0.22a
	N	7.90±0.06a	183.11±4.49c	33.15±1.60c	3.16±0.10b	16.86±0.17b	3.63±0.01b	19.18±0.84a
	NPK	7.94±0.08a	217.38±0.00b	40.46±1.93b	3.51±0.08a	17.25±0.53b	3.89±0.07a	19.17±1.23a

	NPKM	7.85±0.06a	229.14±5.09a	45.13±0.23a	3.61±0.09a	18.15±0.11a	3.84±0.05a	19.99±0.50a
NW	CK	7.72±0.04a	171.36±4.49c	31.62±1.66c	3.06±0.04d	14.20±0.69c	3.69±0.08c	17.77±0.14b
	N	7.68±0.01ab	180.17±4.82bc	31.77±1.04c	3.37±0.07c	15.74±0.85b	3.77±0.04b	17.92±0.31b
	NPK	7.69±0.06ab	186.05±4.49b	37.22±1.86b	3.64±0.04b	16.71±0.16ab	3.78±0.09b	18.20±0.32b
	NPKM	7.60±0.06b	203.68±3.39a	48.36±1.11a	3.89±0.04a	17.39±0.23a	4.22±0.03a	18.68±0.41a
Analysis of variance	T	89.285**	109.354**	0.001	21.260**	16.984**	52.585**	18.323**
	F	3.598*	118.718**	156.288**	68.885**	50.750**	83.448**	3.370*
	T×F	0.126	15.020**	6.207**	0.741	0.393	23.216**	0.176

*Numbers with different letters are significantly cifferent at p <0.05 (LSD). Mean ± standard error of the mean (SEM) (n = 5). The last three lines indicate the significance of the influence of the two factors and their interactions; T: warming effect; F: fertilization effect; T × F: interaction effect between the temperature and fertilization; AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure. AK: available potassium; AP: available phosphorus; NH4^{+}-N: ammonium nitrogen; NO3^{-}-N: nitrate nitrogen; TN: total nitrogen; SOM: organic matter. （the same below）

Table 3. Effects of night-time warming and different fertilization regimes on soil properties of BM

Temperature	Fertilization	pH	AK mg·kg^{-1}	AP mg·kg^{-1}	NH$_4^+$-N mg·kg^{-1}	NO$_3^-$-N mg·kg^{-1}	TN g·kg^{-1}	SOM g·kg^{-1}
AMB	CK	6.87±0.01a	129.05±4.92c	10.61±0.48c	3.41±0.07b	12.15±0.33b	1.51±0.03c	9.61±0.35b
	N	6.82±0.03ab	131.42±3.37c	26.00±0.55b	3.42±0.10b	13.56±0.43a	1.66±0.06b	10.15±0.51ab
	NPK	6.81±0.02b	142.96±11.50b	26.77±1.02b	3.46±0.01b	13.10±0.28a	1.72±0.10b	10.53±0.40a
	NPKM	6.85±0.03ab	164.51±3.59a	30.49±2.22a	3.61±0.10a	13.37±0.52a	1.85±0.06a	10.29±0.22ab
NW	CK	6.83±0.05a	116.86±4.02b	14.04±0.98c	3.36±0.04c	11.06±0.17c	2.28±0.10c	9.72±0.28a
	N	6.74±0.02b	128.28±3.74a	20.91±0.88b	3.39±0.06c	11.55±0.32b	2.32±0.09c	9.92±0.17a

Table 4. Alpha diversity index table of soil fungi of XC

Temperature	Fertilization	Ace	Chao	Shannon	Simpson
AMB	CK	728.08±41.10b	722.31±43.07b	4.14±0.01a	0.0399±0.0031a
	N	774.87±14.45b	781.67±18.16b	4.18±0.18a	0.0354±0.0008b
	NPK	752.42±18.58b	770.96±30.17b	4.21±0.14a	0.0325±0.0007b
	NPKM	867.64±23.13a	890.56±42.51a	4.27±0.12a	0.0282±0.0005c
NW	CK	722.50±31.30c	715.38±25.02c	4.22±0.04b	0.0327±0.0003a
	N	811.13±25.17b	827.26±12.64b	4.30±0.00a	0.0306±0.0019a
	NPK	762.63±9.16bc	782.51±18.84b	4.36±0.08a	0.0286±0.0035a
	NPKM	893.20±29.94a	889.34±35.24a	4.33±0.03a	0.0289±0.0009a
Analysis of variance	T	2.435	0.944	6.904*	23.238**
	F	39.475**	31.901**	2.032	17.986**
	T×F	0.735	0.871	0.262	4.246*

T: temperature, F: fertilization, * and ** indicate significant differences at the 0.05 and 0.01 levels, respectively, the same as below. AMB: ambient; NW: nighttime warming; CK: control; N:

application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.

Table 5. Alpha diversity index table of soil fungi of BM

Temperature	Fertilization	Ace	Chao	Shannon	Simpson
AMB	CK	400.85±14.83b	410.52±21.90c	3.35±0.29b	0.1279±0.0036a
	N	513.94±38.19a	515.07±13.36b	3.68±0.15ab	0.0888±0.0019b
	NPK	497.55±22.80a	516.77±6.12b	3.80±0.09a	0.0693±0.0015d
	NPKM	540.66±14.43a	576.87±14.91a	3.74±0.11a	0.0783±0.0017c
NW	CK	485.03±9.09b	488.21±13.61b	3.78±0.18a	0.0801±0.0053a
	N	519.79±20.98b	525.54±21.77b	3.91±0.05a	0.0701±0.0054b
	NPK	574.75±10.52a	598.52±11.65a	4.05±0.19a	0.0491±0.0038c
	NPKM	568.94±34.15a	524.28±26.32b	3.89±0.11a	0.0724±0.0026b
Analysis of variance	T	25.796**	16.264**	16.052**	318.936**
	F	25.938**	46.273**	5.061*	204.428**
	T×F	3.89*	19.151**	0.824	46.028**

T: temperature, F: fertilization, * and ** indicate significant differences at the 0.05 and 0.01 levels, respectively, the same as below. AMB: ambient; NW: nighttime warming; CK: control; N: application of mineral N fertilizers; NPK: application of mineral N, P and K fertilizers; NPKM: manure fertilizer and NPK plus manure.