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Effects of long-term fertilizer practices on rhizosphere soil ammonia oxidizer community structure under the double-cropping rice field

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Ammonia oxidation plays a vital role in regulating soil nitrogen (N) cycle in agricultural soil, which is significantly influenced by different fertilizer regimes. However, there is still need to further investigate the effects of different fertilizer managements on rhizosphere soil ammonia-oxidizing archaea (AOA) and bacteria (AOB) community in the double-cropping rice field. Therefore, the effects of different long-term (37 years) fertilizer managements on rhizosphere soil potential nitrification activity (PNA), AOA and AOB community structure, and its relationship under the double-cropping rice system in southern of China were studied in the present paper. The field experiment included without fertilizer input as a control (CK), inorganic fertilizer (MF), rice straw and inorganic fertilizer (RF), 30% organic manure and 70% inorganic fertilizer (OM). This result indicated that rhizosphere soil organic carbon (SOC) (SOC), total N and ammonium N (NH_4^+-N) contents in paddy field with RF and OM treatments were increased. Rhizosphere soil PNA, potential nitrification rate (PNR) and abundance of AOB in paddy field with MF treatment were increased, and abundance of AOA in paddy field with RF and OM treatments were increased, respectively. The result also showed that rhizosphere soil diversity index of AOA and AOB with RF and OM treatments were enhanced, compared with CK treatment. Rhizosphere soil AOB and AOA community composition was dominated by *Proteobacteria*, *Actinobacteria* and *Acidobacteria* with all fertilizer treatments. There had significantly positively correlation between the abundance of AOA and SOC, total N, and NH_4-N contents. However, there had significantly negatively correlation between soil pH and abundance of AOA, soil PNA, PNR. As a result, long-term application of rice straw and organic manure was benefit for increasing community structure of rhizosphere soil ammonia oxidizer under the double-cropping rice system in southern of China.

It is widely believed that microbial ammonia oxidation plays an important role in regulating nitrogen (N) cycle of agricultural soil, which were regulated nitrous oxide (N_2O) and N_2 gas emission in the global[1]. Therefore, the biogeochemical cycling of carbon (C), N, phosphorus (P), and sulfur (S) is primarily influenced by soil microbes[2,3]. The rhizosphere, which is the volume of soil adjacent to and affected by plant root[4], plays a vital role in regulating plant growth and soil fertility[3]. Meanwhile, it was a benefit practices for increasing soil fertility and crop yield with fertilizer input, which strongly influence on soil biochemical and biological properties. Therefore, the effects of different fertilizer managements on activity and community structure of soil ammonia-oxidizing archaea (AOA) and bacteria (AOB) were focus on by more and more researcher in recent years[5,6].

In the previous studies, these results indicated that composition and community structure of soil AOA and AOB were mainly affecting by different field managements, such as cropping system, tillage, fertilizer regime, irrigation and so on. Fertilizer regime was playing a vital role in regulating AOA and AOB community in paddy field. Previous results proved that soil ammonia oxidizer population, potential nitrification activity (PNA) and potential nitrification rate (PNR) were changed under applied with inorganic fertilizer and organic manure conditions[7–9]. Some results showed that AOB population and nitrification activity were enhanced with inorganic

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fertilizer practices[8,10], whereas other result indicated that nitrification activity and abundances of AOA and AOB with organic manure management were higher than that of inorganic fertilizer management[11]. Rhizosphere is a zone of intense microbial activity that could profound influences on soil nutrient cycling and provides soil nutrient for plant growth[12]. Some results indicated that nitrifying population[13,14] and PNA[7,9] in rhizosphere soil with inorganic fertilizer, crop residue and organic manure input practices were increased. However, most researches were conducted on bulk soil or based on short-term experiment, there is still need to further investigate the change of rhizosphere soil ammonia oxidation in paddy field under long-term fertilization condition.

Rice (*Oryza sativa* L.) is the main agricultural land use in the tropical and subtropical monsoon regions[15]. It was a vital factor in maintaining or increasing soil quality and fertility of paddy field with different fertilizer regimes, including manure, crop residue and chemical fertilizer. In the previous studies, our result indicated that soil chemical properties (e.g., soil pH, total N, SOC contents) and rice yield were significantly changed under different long-term fertilizer conditions[16,17]. Furthermore, rhizosphere soil total N content, organic N fraction and N mineralization in the double-cropping rice field were obviously increased with manure and crop residue input managements, which in turn influence the function and community structure of AOA and AOB. However, it is still not known how about rhizosphere soil PNA and PNR, diversity and community of AOA and AOB responds to different fertilizer managements under the double-cropping rice system in southern of China. Therefore, the objectives of this study were: (1) to explore the effects of different fertilizer treatments on rhizosphere soil PNA and PNR in the double-cropping rice field, (2) to investigate the rhizosphere soil diversity and community of AOA and AOB in paddy field; (3) to analysis the relationship between soil chemical properties and community of ammonia oxidation under the double-cropping rice system in southern of China.

Materials and methods
Sites and cropping system
The field experiment was beginning from 1986. It was located in Ningxiang City (28°07′ N, 112°18′ E) of Hunan Province, China. Under a continental monsoon climate, the annual mean precipitation and potential evapotranspiration is 1553 mm and 1354 mm, respectively. The monthly mean temperature is 17.2 °C. Soil chemical characteristics at 0–20 cm layer beginning of this field experiment, cropping system were described as by Tang et al.[16].

Experimental design
The field experiment included four treatments: without fertilizer input as a control (CK), inorganic fertilizer (MF), rice straw and inorganic fertilizer (RF), 30% organic manure and 70% inorganic fertilizer (OM). The experiment design ensured all fertilizer treatments received the same level of nitrogen (N), phosphorus pentoxide (P_2O_5), potassium oxide (K_2O) (the amount of N, P_2O_5, K_2O in chemical fertilizer plus that from rice residue or manure) during the early rice and late rice whole growing season, respectively. The kinds of N, P_2O_5, K_2O chemical fertilizer included urea, ordinary superphosphate and potassium chloride, respectively. Other more detail information about the fertilizer managements and field practices were described as by Tang et al.[16].

Soil sample collected
Soil samples were collected at tillering stage of late rice in 25 August 2022. Rhizosphere soil was operationally defined as soil adhering to rice root after gentle shaking. In order to obtain enough rhizosphere soil for analysis at laboratory, twenty rice plants were randomly selected from each plot, and these rhizosphere soils were pooled to form one composite sample. Thus, three composite soil samples of each fertilizer treatment were collected at sampling time, and the total number of 12 composite soil samples were collected at tillering stage of late rice. The fresh soil samples were placed immediately in ice box and transported to the laboratory. Plant root and small stone were removed, one part of soil samples were through a 2-mm sieve then stored at room temperature until chemical analysis, and another part of soil samples were stored at − 20 °C until molecular analysis.

Soil laboratory analysis
Soil chemical properties analysis
Soil pH was measured with a compound electrode (PE-10, Sartorious, Germany) using a soil to water ratio of 1: 2.5. Soil organic carbon (SOC) content was determined by dichromate oxidation, while total N content was measured using a vario MACRO cube element analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). Soil ammonium N (NH_4^+-N) and nitrate N (NO_3^--N) contents were determined by extracting the soil with 0.01 M $CaCl_2$ solution (1:10, w/v) for 30 min and then determining the NH_4^+ and NO_3^- concentrations using a flow injection autoanalyzer (FLA star 5000 Analyzer, Foss, Denmark).

Soil potential nitrification activity (PNA) and potential nitrification rate (PNR)
Soil PNA ($\mu g\ NO_3^-$-N $g^{-1}\ h^{-1}$) was determined with the shaken slurry method described as by Hart et al.[18], which evaluate the maximum nitrate production rate of a soil sample. Soil PNR was investigated with griess reagent colorimetry method described as by Kurola et al.[19].

DNA extraction and PCR amplification
Soil total DNA was extracted using a Fast DNA SPIN Kit for soil (MP Biomedicals, Illkirch, France) according to the manufacturer's instruction. DNA was finally eluted with 100 μL of the DNA elution solution included in the kit. Soil DNA extraction was characterized by using electrophoresis on 0.7% (wt/vol) agarose gels.

Polymerase chain reaction (PCR) reaction mixture included 12.5 μL 2 × EasyTaq PCR SuperMix (TransGen Biotech, Beijing, China), 0.5 μM of each primer, 1 μL of 10-fold diluted DNA template, and diluted to a final volume of 25 μL. PCR reaction was performed using the AOB-specific primers CTO654r and CTO189f[20], AOA

amoA genes were amplified using primers CrenamoA616r and CrenamoA23f[21]. The size and quality of soil PCR products were verified with 1.5% (wt/vol) agarose.

Quantitative real-time PCR
In order to investigate of soil sample ammonia-oxidizing archaea community, bacteria community was analysis using the primers CrenamoA616r and CrenamoA23f, CTO654r and CTO189f, respectively[22]. Quantitative real-time PCR for AOB and AOA was conduct in triplicate using an ABI 7500 Real-Time PCR System (Applied Biosystems) under the following thermocycling conditions: 30 s at 95 °C, followed by 40 cycles of 5 s at 95 °C and 34 s at 60 °C. The amplification specificity of AOA was confirmed by generating a melting curve. Standard curves ranging from 1×10^2 to 1×10^7 copies were prepared by 10-fold serial dilution of known copy numbers of plasmid DNA possessing the genes of interest. In order to calculate abundances of AOA and AOB genes, it was assumed that AOA carry one copy of the *amoA* gene per cell[23], and AOB contain one copy of 16 S rRNA per cell[24]. The sequences of AOA and AOB were then compared with those available in the National Center for Biotechnology Information (NCBI) GenBank database using the BLAST algorithm. Sequence analysis and operational taxonomic units (OTUs) identification were according to the method described as by Fagen et al.[25]. Matches were filtered at 80% length fraction and OTUs were classified at 97% identity level. Richness diversity, Shannon diversity and Chao 1 diversity index were used to calculate the diversity of ammonia-oxidizing archaea and bacteria community using the Mothur software[26].

Statistical analysis
These results of every investigate items were presented as average value and standard error. The significance of differences between different fertilizer treatments was conducted using analysis of variance (ANOVA). The relationship between soil chemical properties, soil potential nitrification activity, soil potential nitrification rate and abundances of AOA and AOB were analyzed using the Pearson correlation test. All statistical analyses were calculated by using SAS 9.3 software package[27] and a probability value of 0.05 was considered to indicate statistical significance.

Results
Soil chemical properties
This result indicated that rhizosphere soil chemical characteristics in paddy field were obvious changed under different long-term fertilizer conditions (Table 1). The result showed that soil pH value in paddy field with OM and RF treatments was significantly ($p < 0.05$) higher than that of CK treatment. SOC, soil NO_3-N and NH_4-N contents with MF, RF and OM treatments were significantly ($p < 0.05$) higher than that of CK treatment. The result showed that soil total N content in paddy field with OM and RF treatments was significantly ($p < 0.05$) higher than that of MF and CK treatments (Table 1).

Soil potential nitrification rate and potential nitrification activity
The effects of different fertilizer treatments on rhizosphere soil potential nitrification activity (PNA) and potential nitrification rate (PNR) in paddy field were showed as in Fig. 1. This result showed that rhizosphere soil PNA with all fertilizer treatments ranged from 1.96 to 3.11 µg NO_3^--N g^{-1} h^{-1} (Fig. 1a). Soil PNA with MF treatment was significantly ($p < 0.05$) higher than that of RF, OM and CK treatments. Soil PNA with RF and OM treatments was significantly ($p < 0.05$) higher than that of CK treatment.

This result showed that rhizosphere soil PNR with all fertilizer treatments ranged from 0.34 to 0.51 µg g^{-1} h^{-1} (Fig. 1b). Soil PNR with MF treatment was significantly ($p < 0.05$) higher than that of RF, OM and CK treatments. Soil PNR with RF and OM treatments was significantly ($p < 0.05$) higher than that of CK treatment, but there were no significantly difference ($p > 0.05$) in soil PNR between RF and OM treatments.

Abundances of AOA and AOB genes
The effects of different fertilizer treatments on abundances of rhizosphere soil AOA and AOB genes in paddy field were showed as in Fig. 2. This result showed that abundance of AOA with all fertilizer treatments ranged from 81.79 to 143.75 copies $\times 10^7$ cells g^{-1} soil (Fig. 2a). Abundance of AOA with RF and OM treatments was significantly ($p < 0.05$) higher than that of MF and CK treatments. Compared with CK treatment, abundance of AOA with MF, RF and OM treatments increased by 1.25, 1.62 and 1.76 times, respectively.

Treatments	pH	SOC (g kg^{-1})	Total *N* (g kg^{-1})	NO$_3$-*N* (g kg^{-1})	NH$_4$-*N* (g kg^{-1})
MF	6.32 ± 0.17ab	21.46 ± 0.68c	2.07 ± 0.06c	0.17 ± 0.01c	0.16 ± 0.01c
RF	6.70 ± 0.17a	24.82 ± 0.72b	2.45 ± 0.07b	0.21 ± 0.01b	0.20 ± 0.01b
OM	6.81 ± 0.18a	29.62 ± 0.71a	3.08 ± 0.08a	0.27 ± 0.01a	0.23 ± 0.01a
CK	6.21 ± 0.16b	19.68 ± 0.56d	1.91 ± 0.06c	0.13 ± 0.01d	0.12 ± 0.01d

Table 1. Effects of different long-term fertilizer treatments on soil chemical characteristics in the double-cropping rice field. Values were presented as mean ± standard error. Different lowercase letters in the same column were indicated significantly at difference in 0.05 levels. The same as below. MF, inorganic fertilizer; RF, rice straw and inorganic fertilizer; OM, 30% organic manure and 70% inorganic fertilizer; CK, without fertilizer input as a control.
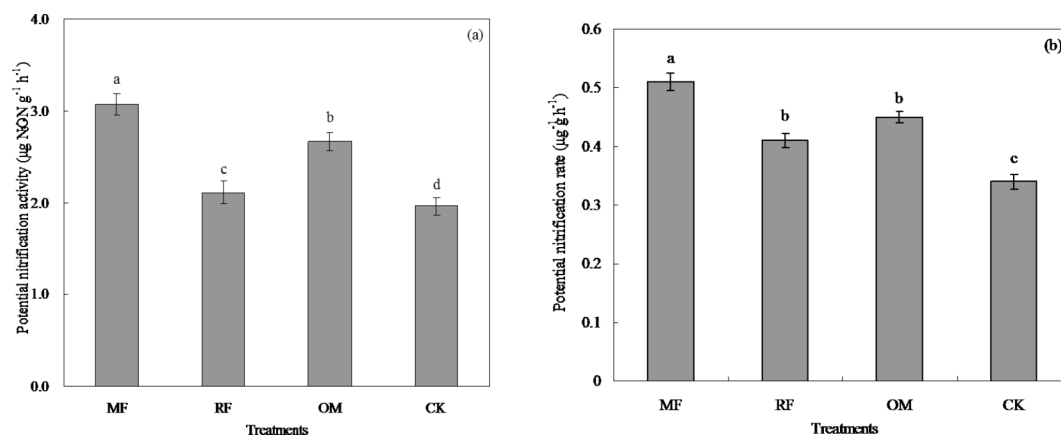
Fig. 1. Potential nitrification activity (a) and potential nitrification rate (b) in rhizosphere soil under different fertilizer treatments. MF: inorganic fertilizer; RF: rice straw and inorganic fertilizer; OM: 30% organic manure and 70% inorganic fertilizer; CK: without fertilizer input as a control. Vertical bars represent the standard error. Different lowercase letters were indicated significantly at difference among fertilizer treatments in 0.05 levels. The same as below.
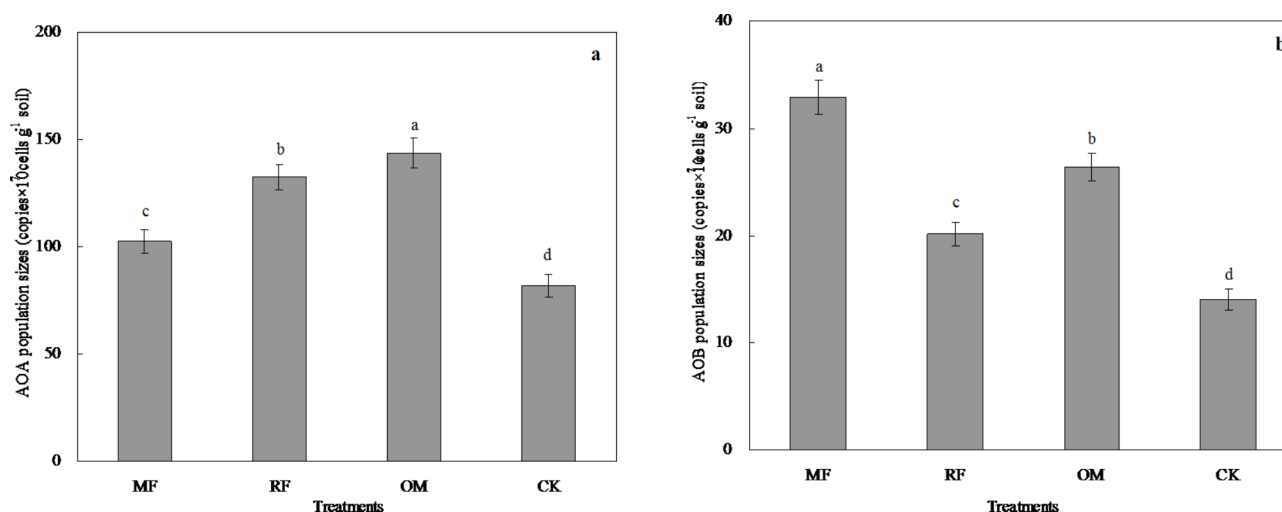

Fig. 2. Effects of different long-term fertilizer treatments on abundances of AOA (a) and AOB (b) in rhizosphere soil under the double-cropping rice system.

This result showed that abundance of AOB with all fertilizer treatments ranged from 14.05 to 32.87 copies$\times 10^7$ cells g^{-1} soil (Fig. 2b). Abundance of AOB with MF treatment was significantly ($p < 0.05$) higher than that of RF, OM and CK treatments. Compared with CK treatment, abundance of AOB with MF, RF and OM treatments increased by 2.34, 1.44 and 1.88 times, respectively.

Diversity index of AOA and AOB

The effects of different fertilizer treatments on rhizosphere soil diversity index of AOA and AOB were showed as in Table 2. Soil Richness diversity index of AOA with RF and OM treatments was significantly ($p < 0.05$) higher than that of CK treatment, soil Shannon and Chao 1 diversity index of AOA with OM treatment was significantly ($p < 0.05$) higher than that of CK treatment, respectively.

This result indicated that rhizosphere soil Richness and Shannon diversity index of AOB with OM treatment was significantly ($p < 0.05$) higher than that of MF and CK treatments. Soil Chao 1 diversity index of AOB with RF and OM treatments was significantly ($p < 0.05$) higher than that of MF and CK treatments, but there had no significantly ($p > 0.05$) difference in soil Chao 1 diversity index of AOB between OM and RF treatments (Table 2).

Bacteria and archaea	Diversity parameters	Treatments			
		MF	RF	OM	CK
AOA	Richness indices	12.52 ± 0.37b	12.96 ± 0.38a	13.25 ± 0.38a	12.27 ± 0.35b
	Shannon indices	2.59 ± 0.07ab	2.63 ± 0.07ab	2.79 ± 0.08a	2.48 ± 0.06b
	Chao 1 indices	5.26 ± 0.16b	5.62 ± 0.16b	6.29 ± 0.18a	4.47 ± 0.13c
AOB	Richness indices	9.37 ± 0.27b	9.82 ± 0.28b	10.43 ± 0.31a	8.98 ± 0.26c
	Shannon indices	2.68 ± 0.07b	2.95 ± 0.08ab	3.12 ± 0.09a	2.74 ± 0.07b
	Chao 1 indices	3.37 ± 0.10b	3.72 ± 0.11a	3.89 ± 0.11a	2.94 ± 0.08c

Table 2. Soil diversity index of AOA and AOB with different long-term fertilizer treatments. AOA, soil ammonia-oxidizing archaea; AOB, soil ammonia-oxidizing bacterial. Different lowercase letters in the same line indicated significantly difference at $p < 0.05$. The same as below.
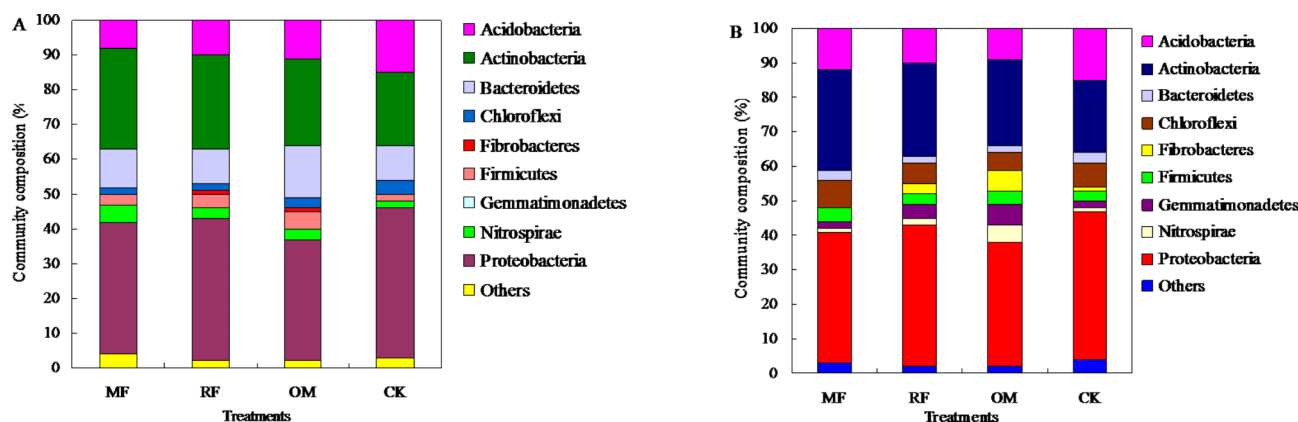

Fig. 3. Community compositions of AOA (a) and AOB (b) in rhizosphere soil under different long-term fertilizer treatments.

Items	pH	SOC	TN	NH$_4$-N	NO$_3$-N	AOA	AOB
AOB	− 0.425	0.301	0.327	0.287	− 0.195	0.285	—
AOA	− 0.702**	0.706**	0.715**	0.734**	0.406	—	0.284
PNA	− 0.611*	0.352	0.438	0.243	− 0.275	0.347	0.872**
PNR	− 0.605*	0.326	0.375	0.136	− 0.231	0.284	0.836**

Table 3. Correlation between soil chemical properties, potential nitrification activity (PNA), potential nitrification rate (PNR) and abundances of AOA and AOB. TN: soil total nitrogen content; SOC: soil organic carbon. AOB: soil ammonia-oxidizing bacterial; AOA: soil ammonia-oxidizing archaea; PNA: soil potential nitrification activity; PNR: potential nitrification rate. *, ** were significantly at the 0.05 and 0.01 level, respectively.

Community structure of AOA and AOB

This result indicated that rhizosphere soil ammonia-oxidizing archaea community composition was *Proteobacteria*, *Actinobacteria*, *Bacteroidetes*, *Acidobacteria*, and *Nitrospirae*. The *Proteobacteria* and *Actinobacteria* occupy absolute advantage in rhizosphere soil with all fertilizer treatments (Fig. 3A).

The main community composition rhizosphere soil ammonia-oxidizing bacterial community composition was *Proteobacteria*, *Actinobacteria*, *Acidobacteria*, *Chloroflexi*, and *Firmicutes* with all fertilizer treatments. The *Proteobacteria*, *Actinobacteria* and *Acidobacteria* occupy absolute advantage in rhizosphere soil with MF, RF and OM treatments. This result showed that community composition of soil *Actinobacteria* with MF, RF, OM treatments were higher than that of CK treatment (Fig. 3B).

Correlations of soil properties with community structures of AOA and AOB

There had significantly positively ($p < 0.01$) correlation between abundance of AOA and SOC, total N, NH$_4$-N contents (Table 3). Meanwhile, there had significantly negatively ($p < 0.05$) correlation between abundance of AOB and soil potential nitrification activity, potential nitrification rate. However, there had significantly negatively ($p < 0.05$) correlation between soil pH and abundance of AOA, soil potential nitrification activity,

potential nitrification rate. There had not correlation between abundance of AOA and soil PNA, PNR. There had significantly positively ($p < 0.01$) correlation between abundance of AOB and soil PNA, PNR.

Discussions

In the previous studies, these results indicated that rhizosphere soil microbial activity was affected during N transformation processes in paddy field[7,14]. In this study, our result showed that rhizosphere soil potential nitrification activity (PNA) and potential nitrification rate (PNR) in paddy field were obvious changed in different fertilizer treatments (Fig. 1), implying a profound fertilization effect on rhizosphere soil ammonia oxidation. Meanwhile, soil PNA and PNR in paddy field with MF treatment were significantly increased, compared with RF, OM and CK treatments. These results were consistent with previous results of paddy field in China[28]. The reason maybe attributed to that higher resource of rhizodeposition after mineralization may provide more substrate for ammonia oxidizers and stimulate microbial growth[28,29]. On the other hand, soil nitrification and ammonia oxidizers were frequently influenced by the rice varieties and climate factors, which were regarded as important environmental factors responsible for microbial nitrification[30]. Furthermore, there had significantly positively correlation between abundance of AOB and soil PNA, PNR. Meanwhile, there had significantly negatively correlation between soil pH and soil PNA, PNR. These results suggested that soil pH and abundance of AOB were important drivers in regulating soil PNA and PNR under the double-cropping rice system in southern of China.

Our result showed that abundance of AOA was higher than that of AOB in rhizosphere soil, which were agree with previous reported by Chen et al.[28]. However, the community structure and abundance of AOB were significantly correlated with soil PNA and PNR, while those of AOA were not (Table 2; Fig. 2), suggesting that soil nitrification were primarily driven by AOB in the double-cropping rice paddy field. The predominance of bacterial nitrification were consistent with previous result[31], but inconsistent with report for acidic soil in paddy field[32], suggesting that soil texture, soil characteristics and soil pH were obvious difference from the present experimental field. Further results suggested that archaea can be well adapted to extreme conditions, such as soil type, soil pH, low ammonia availability, and climate conditions[19,33], while the opposite response were detected for bacteria[11]. These soil texture and soil characteristics were main explain why AOB but not AOA play a vital role in regulating soil nitrification in this field experiment (pH from 6.21 to 6.81) (Table 1) under long-term fertilizer condition.

In the present study, our result indicated that abundance of AOA in rhizosphere soil were higher than that of AOB in paddy field, which were consistent with the previous result[11]. The reason maybe attributed to that soil pH of paddy field was greatly impacted by fertilizer managements (Table 1), possibly owing to strong carbonate buffering[2]. It had proved that soil pH had a considerable effect on activity of AOB and other microbial processes that they mediate[6]. In this study, the result indicated that abundance of AOB with MF treatment were significantly increased compared with RF and OM treatments, which were agree with previous study[21], who found that N-induced stimulation of AOB under long-term inorganic fertilizer input condition. The reason was attributed to that dependence of monooxygenase on NH_3, which would be ionized exponentially to NH_4^+ with decreasing pH in paddy field under long-term inorganic fertilizer input condition, but soil acid buffering capacity and soil pH were increased under long-term rice straw and organic manure input conditions[11]. Meanwhile, this result indicated that abundance of AOA with RF and OM treatments were higher than that of MF and CK treatments, which suggested there had higher soil organic carbon, total N contents and soil pH with organic manure and rice straw input practices, may stimulate growth of the AOA community. Compared with RF and OM treatments, abundance of AOA with MF treatment were decreased, which suggested there had lower soil organic carbon, total N contents and soil pH with long-term inorganic fertilizer input practice, may restricted growth of the AOA community[28]. Positively correlation between abundance of AOA and SOC, total N contents were also observed in the present study (Table 3), which suggested that AOA and AOB have alternative growth strategies for mixotrophic or heterotrophic growth[10].

Previous studies results indicated that soil functional community involved in ammonia oxidizer respond different to fertilizer practices change[7,9]. In the present study, our result showed that diversity of ammonia oxidizer community (Richness index, Shannon index and Chao 1 diversity index) was significantly changed among the different fertilizer regimes. Our result indicated that long-term application of rice straw and organic manure was result in increased diversity of AOA and AOB community (Table 2). The reason maybe attributed to that soil texture and nutrient content were increased in the double-cropping rice paddy field under long-term application of rice straw and organic manure conditions[16,17], which decreased in the competitive niche exclusion and selection mechanism between soil ammonia-oxidizing bacterial and archaea populations. Therefore, these consequences could lead to changes in ammonia-oxidizing bacterial and archaea diversity, and enhance in the Richness, Shannon and Chao 1 indices[19]. Meanwhile, this result indicated that diversity of ammonia oxidizer community with MF treatment were higher than that of CK treatment. The reason maybe attributed to that application of inorganic fertilizer practice, which caused promoted soil chemical properties and rhizosphere soil environment than the without fertilizer input practice did, could promoted in multiplying soil ammonia-oxidizing bacterial and archaea[4,11]. Therefore, this study supports the view that application of rice residue and manure treatments strongly influence on soil texture and altered soil chemical properties, causing changes in diversity and abundances of soil ammonia-oxidizing bacterial and archaea.

In the previous studies, these results indicated that soil AOB and AOA community composition was main influenced by different fertilizer treatments[20,30]. In this study, the result revealed that rhizosphere soil AOB and AOA community composition were dominated by *Proteobacteria*, *Actinobacteria* and *Acidobacteria* with fertilizer treatments (MF, RF and OM treatments), this findings were agree with the previous found[7,9]. The reason maybe attributed to that *Proteobacteria*, *Actinobacteria* and *Acidobacteria* were considered as the eutrophic bacteria in soil, which were using total N, NH_4^+-N and NO_3^--N contents as main N source and growth

rapidly under nutrient rich conditions. On the other hand, rhizosphere soil physical and chemical properties were important factors in influencing soil microbial abundance and community under application of fertilizer practice condition. In this study, the result revealed that ammonia oxidizer community were correlated with soil chemical properties (Table 3), implying that soil ammonia-oxidizing bacterial and archaea community in the double-cropping rice field were changed by combined effect of soil pH, SOC, total N, NH_4^+-N, NO_3^--N contents, soil PNA and PNR. These results were supported by the observation that AOA and AOB abundances were negatively correlated with soil pH[33,34], but positively correlated with SOC, total N and NH_4^+-N contents (Table 3). However, the controlling factor in influencing on ecological function of rhizosphere soil AOB and AOA in paddy field is still need to further study.

Conclusions

Our result indicated that activity and community structure of rhizosphere soil AOB and AOA in paddy field were obvious changed under different long-term of fertilization conditions. Rhizosphere soil potential nitrification activity and potential nitrification rate in paddy field were stimulated by application of inorganic fertilizer practice. Abundances of rhizosphere soil AOA and AOB genes in paddy field with MF, RF and OM treatments were significantly increased, compared with CK treatment. Long-term (37 years) application of chemical fertilizer increase soil PNA and abundance of AOB, whereas application of rice residue and organic manure significantly enhance abundance of AOA in the double-cropping rice field. Meanwhile, this result indicated that soil Richness, Shannon and Chao 1 diversity indices of AOB and AOA were improved under manure and crop residue input conditions. Rhizosphere soil AOB and AOA community composition were dominated by *Proteobacteria*, *Actinobacteria* and *Acidobacteria* with all fertilizer treatments. However, there is still need to further investigate effects of different fertilizer treatments on specific mechanistic of soil N-cycle ammonia-oxidizing bacterial and archaea based on long-term field experiment.

Data availability

Data is provided within the manuscript.

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Author contributions

Haiming Tang and Li Wen wrote the main manuscript text, Kaikai Cheng and Lihong Shi prepared Figs. 1 and 2, Geng Sun prepared Fig. 3, Mei Sun and Weiyan Li prepared Table 1, and 2. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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