The efficacy of 3,4-dimethylpyrazole phosphate on N_2O emissions is linked to niche differentiation of ammonia oxidizing archaea and bacteria across four arable soils

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Abstract

The effectiveness of nitrification inhibitor, 3,4-dimethylpyrazole phosphate (DMPP) on nitrous oxide (N_2O) emissions varies among soils, due to both abiotic (soil properties) and biotic factors (ammonia oxidizers and denitrifiers). Understanding the nature of these effects is necessary to improve the efficacy of DMPP, therefore improving nitrogen use efficiency and environmental benefits. Our results showed: (i) DMPP effectively inhibited nitrification through inhibiting ammonia oxidizing bacteria (AOB) abundance; (ii) releasing ammonia oxidizing archaea (AOA) from the competition with AOB allowed AOA to efficiently grow and multiply under high ammonium conditions; (iii) abiotic factors played more important roles than biotic factors in soil N_2O emissions.

Keywords: DMPP, nitrous oxide, niche differentiation

1. Materials and Methods

Four contrasting arable soils (a grey desert soil, an alluvial paddy soil, a loess-formed paddy soil, and a red soil) were used for microcosm experiments, including three treatments: (i) nil-treated control, (ii) urea only, and (iii) urea + DMPP. Urea and DMPP were added at a rate of 100 mg N kg^{-1} soil and 1.5% of urea-N, respectively. All assays were performed in triplicate and incubated under 50% water holding capacity in darkness at 25°C for two months.

2. Results

DMPP significantly inhibited nitrification and N_2O emissions, with an average inhibitory rate of 90% for grey desert soil, 80.7% for alluvial paddy soil, 59.7% for loess-formed paddy soil, and 41.7% for red soil. Suppression of N_2O emissions by DMPP occurred alongside reduction in AOB abundance, resulting in increase of AOA abundance. Soil-dependent response patterns to DMPP were observed for community structures of AOA, AOB, *nirS*- and *nirK*-denitrifiers. Partial least squares path modeling (PLS-PM) found that abiotic factors, particularly pH, and biological factors such as ammonia oxidizer communities, were closely linked to N_2O emissions (Fig. 1). Abiotic factors were the primary variable determining the efficacy of DMPP in reducing N_2O emission, with a total effect of –0.609, larger than that of biotic factors (0.547).

3. Conclusions

Our results demonstrated both abiotic and biotic factors are major contributors governing the efficacy of DMPP in abating N_2O emissions across soils, specifically, edaphic properties were of primary importance. Our results reaffirmed that reduction of N_2O emissions by DMPP was primarily due to inhibition of AOB, which led to AOA abundance increased, demonstrating that AOA may be released from competition from AOB and grow in soils with high N conditions. This revealed that a key mechanism explaining why soil AOA generally prefer to low N may be due to competition with AOB.

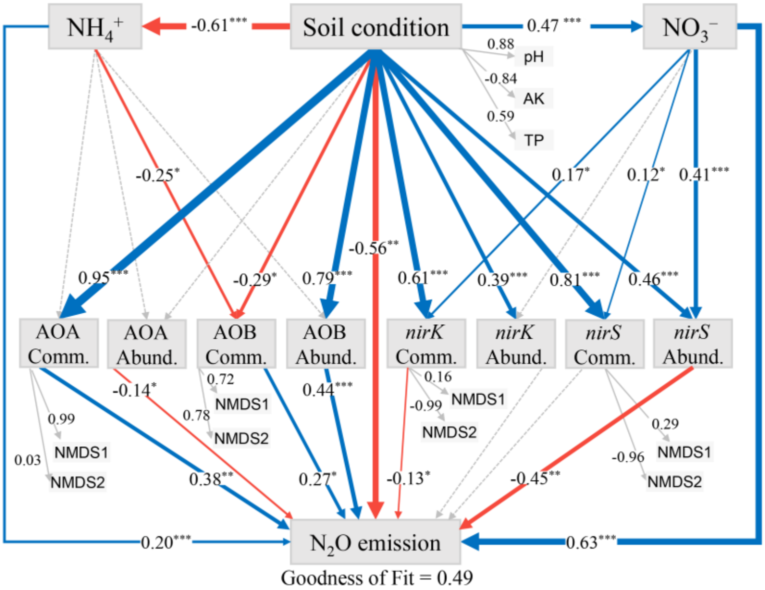

Fig. 1: Directed graph of the partial least squares path model. Coefficients of inner model differ significantly from 0 are indicated by $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

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