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Evidence of aerobic and anaerobic methane oxidation coupled to denitrification in agricultural soils

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Rationale

- Agricultural soils may act as either a source or a sink of atmospheric methane (CH_4).
- Its extent depends on soil type, aeration, water regimes, nutrient availability and environmental variables.
- Advancing research on the interactions between CH_4 oxidation and denitrification is a key concern for understanding global C and N cycles.
- This paper reviews recent progress in their functional relationships.

Relationship between CH_4 oxidation and denitrification

Isotope studies show that CH_4 production and oxidation takes place simultaneously in agricultural soils at water content above field capacity i.e. in presence of anaerobic microsites and aerobic-anaerobic interface (Fig. 1).

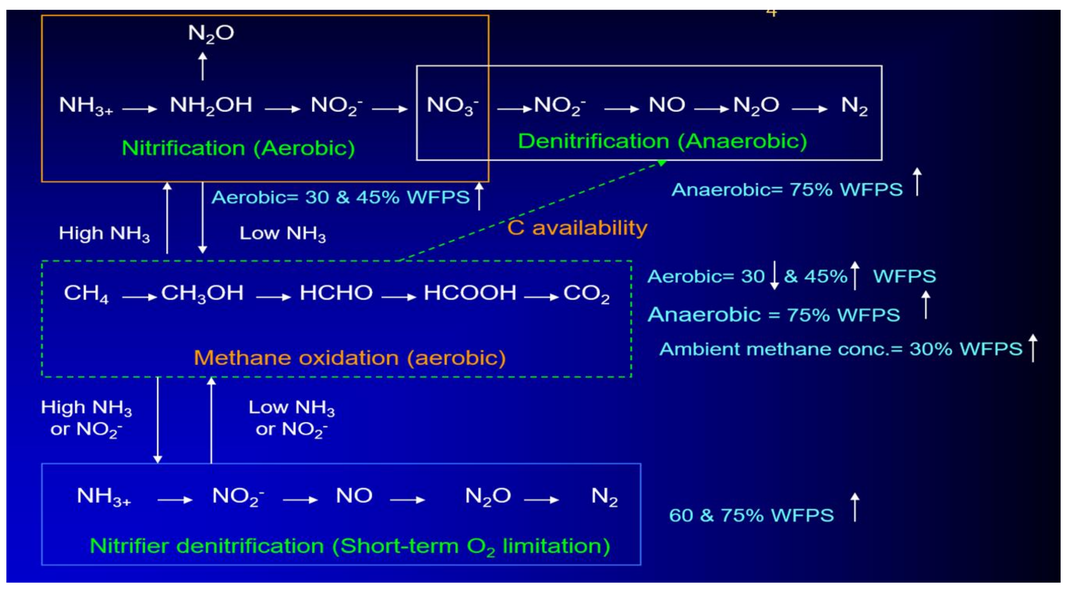

Fig. 1. Conceptual diagram of the effect of soil water on the N transformations and their interaction with CH_4 oxidation (Khalil and Baggs, 2005)

This results in either aerobic or anaerobic CH_4 oxidation coupled to the highest N_2O emissions, demonstrating a close relationship between CH_4 oxidation and denitrification processes.

Pathways of CH_4 oxidation coupled to denitrification

Methane is a low-cost electron donor for coexisting denitrifiers.

Denitrification is coupled to either aerobic CH_4 oxidation involving direct nitrate/nitrite reduction (partial denitrification, Fig. 2), or

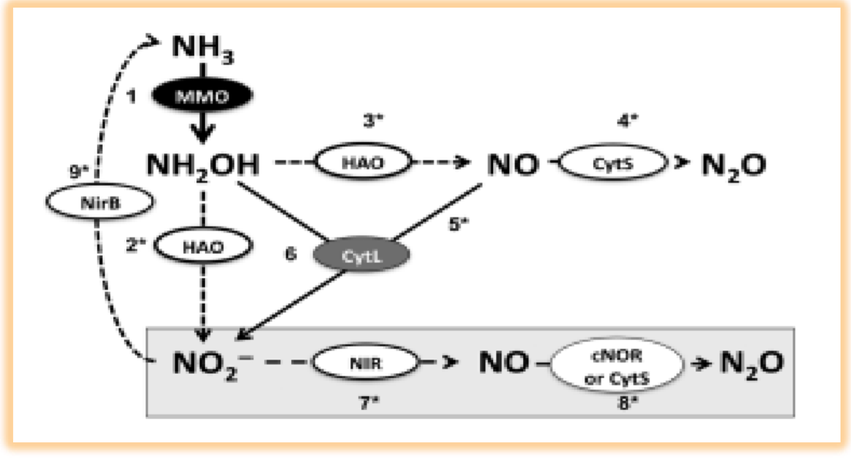

Fig. 1. Pathways and functional gene inventory for nitrification and denitrification in association with methanotrophs (Campbell et al. 2011).
(MMO, methane monooxygenase; HAO, NH_2OH oxidoreductase; CytS, cytochrome c0-b; CytL, cytochrome P460; NIR, NO-forming nitrite reductase (NirK, NirS or Octaheme cytochrome c protein); cNOR, cytochrome c-dependent nitric oxide reductase; NirB, NH_3-forming siroheme nitrite reductase.

anaerobic relating to nitrite/nitric oxide reduction (complete denitrification).

$$3CH_4 + 8NO^-_2 + 8H+ \rightarrow 3CO_2 + 4N_2 + 10H_2O$$
$$5CH_4 + 8NO^-_3 \rightarrow 5CO_2 + 4N_2 + 8OH + H_2O$$

Evidenced by microbial genomics and isotope study

A microbial consortium is involved in the interactive process. Recent research with microbiological techniques prove (Fig. 3):

(i) the occurrence of the coupled process by combining aerobic methanotrophs and denitrifiers, and

(ii) oxidization of ammonium and metabolic by-products, releasing N_2O as a terminal product.

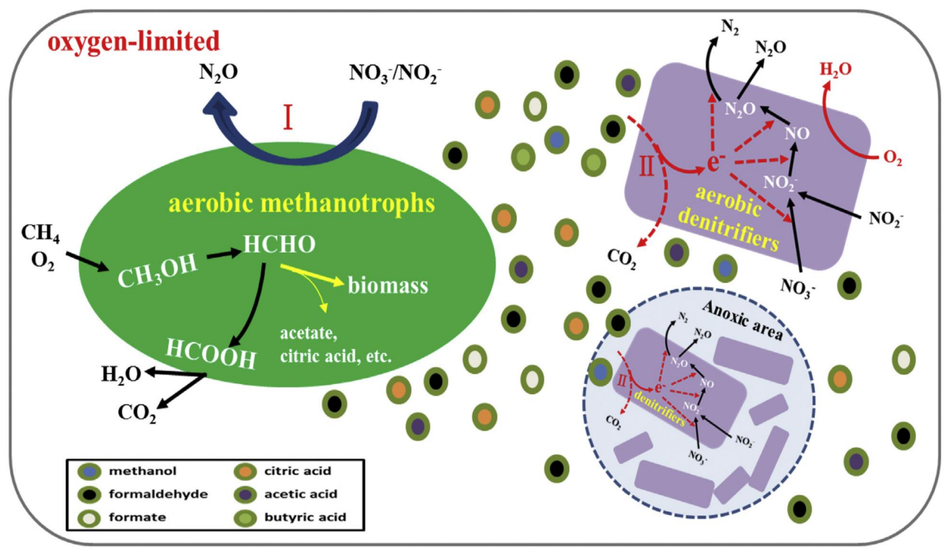

Fig. 3. Postulated pathways aerobic methane oxidation and trophic links between these two processes (Zhu et al. 2016.)

However, the apparent anaerobic phenomenon lacks known genes for dinitrogen (N_2) production.

Isotope studies reveal that methanotrophs could bypass the denitrification intermediate N_2O to produce N_2 and O_2 that oxidizes CH_4 (Fig. 4)

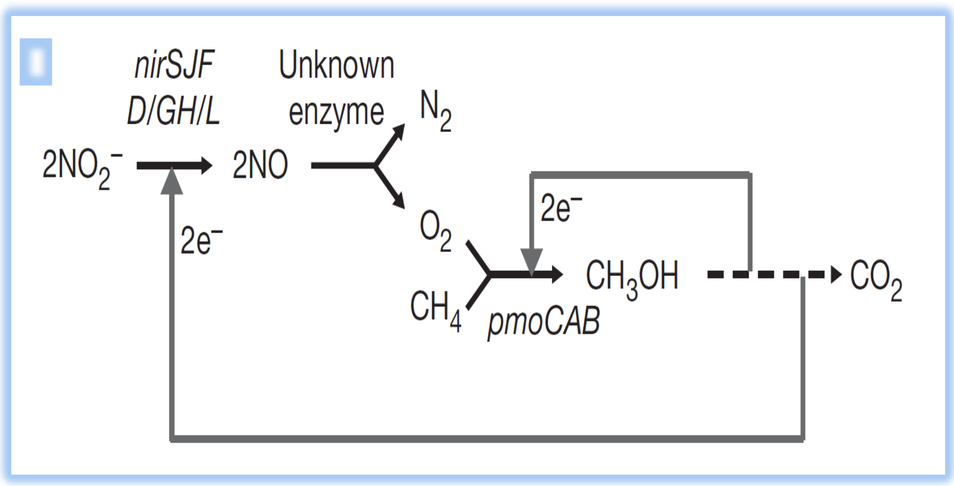

Fig. 4. Pathway of methane oxidation with nitrite (Ettwig et al., 2010).
(nirSJF = nitrite reductase; pmoCAB = particulate methane monooxygenase)

What next?

- Further investigations using both advanced molecular microbiology and isotope tracing techniques are necessary to:
  - elucidate the nature of the processes,
  - better understand the mechanisms in agricultural soils and
  - develop biotechnological solutions to the issues concerning particularly to climate change.

References

Campbell et al. 2011. FEMS Microbiol Lett 322: 82-89
Ettwig et al. 2010. Nature 464: 543-550.
Khalil MI & EM Baggs. 2005. Soil Biology and Biochemistry 37:1785-1794.
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Acknowledgements