Oxygen regulates nitrous oxide production directly in agricultural soils

Xiaotong Song[1], Xiaotang Ju[1*], Cairistiona F.E. Topp[2] and Robert M. Rees[2]

[1] College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China

[2] SRUC, West Mains Road, Edinburgh EH9 3JG, Scotland, U.K.

E-mail: juxt@cau.edu.cn

Abstract

The effects of *in situ* oxygen (O_2) dynamics on nitrous oxide (N_2O) production was investigated in a typical intensively managed Chinese cropping system under a range of environmental conditions (temperature, moisture, ammonium, nitrate, carbon etc.). Soil O_2 concentration was the most significant factor correlating with soil N_2O concentration compared with other environmental factors. Soil N_2O concentration increased exponentially with decreasing soil O_2 concentrations. The exponential model of N treatments predicted 74-90% of variance in soil N_2O concentrations. This study offers new opportunities for developing more sensitive approaches to predicting and through appropriate management interventions mitigating N_2O emissions from agricultural soils.

Keywords: soil oxygen, nitrous oxide, nitrogen fertilization, extreme rainfall, irrigation, *in situ* upland soil

1. Introduction

Soil oxygen (O_2) is the key proximal factor simultaneously controlling nitrification and denitrification at the cellular-level, and further determining the partitioning of the end products between dinitrogen (N_2) and nitrous oxide (N_2O). For a given site, O_2 dynamics would be mainly regulated by changing climate factors within the year (temperature and precipitation), and agronomic management (cropping systems, fertilization, irrigation etc.). Unlike aquatic systems experiencing nearly constant anoxia throughout the year, many agricultural soils have been shown to have both spatially and temporally fluctuating redox status and experience intermittent low redox potentials associated with precipitation or irrigation events (Owens et al., 2016). Knowledge regarding O_2-regulated N_2O production is derived mostly from pure culture and soil microcosm studies (Khalil et al., 2004; Zhu et al., 2013). Given high spatio-temporal heterogeneity of O_2 dynamics in the *in situ* upland agricultural soils in this study, the role of O_2 in regulating N_2O production remains challenging to explain.

2. Objectives

(1) To quantify the effects of soil O_2 and other soil environment variables on N_2O production in the *in situ* upland agricultural soils;

(2) To establish robust empirical models between soil O_2 and N_2O concentrations under the coupling spatio-temporal changes of the climate and management factors.

3. Methods

This study was carried out in treatments of three N levels with straw removal, straw return or manure addition in a long-term wheat-maize double cropping system in North China. We measured soil O_2 and GHGs concentrations at 7-20 cm depth using soil-air equilibration tubes, as well as soil temperature, moisture, mineral nitrogen (including nitrite), dissolved organic carbon or nitrogen, and pH at 0-20 cm depth over one year of 2016-2017.

4. Results

- Climate and management (fertilization, irrigation, precipitation and temperature), and their interactions significantly affected soil O_2 and N_2O concentrations ($P<0.05$) (Fig. 1).
- Soil O_2 concentration was the most significant factor correlating with soil N_2O concentration (r= -0.71) when compared with temperature, water-filled pore space and ammonium concentration (r= 0.30, 0.25 and 0.26, respectively).
- Soil N_2O concentration increased exponentially with decreasing soil O_2 concentrations. (Fig. 2)
- The exponential model of N treatments and fertilization with irrigation/precipitation events predicted 74-90% and 58% of the variance in soil N_2O concentrations, respectively.

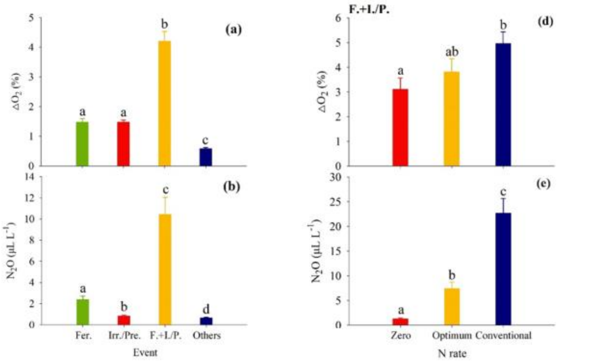

Fig. 1: Average reduction in soil oxygen (O_2) concentration and average soil nitrous oxide (N_2O) concentration at 7-20 cm depth under different agronomic events (a-b) or in different N rates under the Fer.+Irr./Pre. event (d-e) during the period from April 2016 to April 2017. Fer., Irr./Pre., Fer.+Irr./Pre. and Others represent the data covering all treatments measured under fertilization, irrigation or precipitation, fertilization with irrigation or precipitation and other time, respectively.

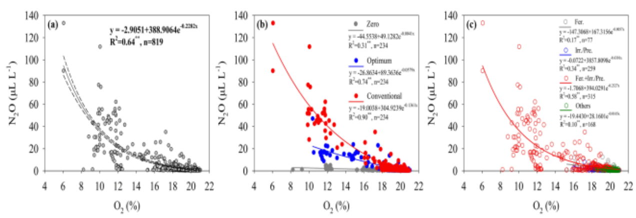

Fig. 2: Response of soil N_2O concentration to soil O_2 concentration at 7-20 cm depth based on all the measurement data (a), data of different N rates (b) or agronomic events (c) during the period from April 2016 to April 2017. Fer., Irr./Pre., Fer.+Irr./Pre. and Others in (c) represent the same as that in Fig. 1.

5. Conclusion

Soil O_2 status is the proximal, direct and the most decisive environmental trigger for N_2O production outweighing the effects of other factors, and could be a key variable integrating the aggregated effects of various complex interacting variables.

Acknowledgements

This study was financially supported by the National Natural Science Foundation of China (41830751), Newton Fund N-Circle project (Grant Ref. BB/N013484/1), Sino-British Joint Research Innovation PhD Exchange Program funded by the China Scholarship Council (201603780112).

References

Owens J, Clough T J, Laubach J, Hunt J E, Venterea R T, and Phillips R L 2016 Nitrous Oxide Fluxes, Soil Oxygen, and Denitrification Potential of Urine- and Non-Urine-Treated Soil under Different Irrigation Frequencies *J. Environ. Qual.* **45** 1169-1177

Khalil K, Mary B, and Renault P 2004 Nitrous oxide production by nitrification and denitrification in soil aggregates as affected by O_2 concentration *Soil Biology and Biochemistry* **36** 687-699

Zhu X, Burger M, Doane T A, and Horwath W R 2013 Ammonia oxidation pathways and nitrifier denitrification are significant sources of N_2O and NO under low oxygen availability *Proc. Natl. Acad. Sci. U. S. A.* **110** 6328-6333