Mn Oxide affects nitrification and N_2O emissions in a subtropical rice soil with variable water regimes

Xiaoping Xin[1,2*] , Jing Su[1], Zhihui Wang[1], Xianjun Jiang[1] , Zhenli He[2]

[1*]College of Resources and Environment, Southwest University, Chongqing 400715, China, Email: xxp1024@yahoo.com
[2]Indian River Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Fort Pierce, FL 34945

Xiaoping Xin

High lights

1. Manganese oxide retarded nitrification rate in aerobic conditions
2. Manganese oxide increased nitrification rate in anaerobic conditions
3. Manganese oxide decreased N_2O emission rate in anaerobic conditions

Introduction

Approximately 155 million ha of land are used for rice cropping, and more than 50% of the world's population feeds on rice, while nitrogen fertilizer-use efficiency in rice-based ecosystems is usually less than half of the efficiency found in other agricultural systems (Roy et al. 2003). The periodic short-term redox cycles induced by paddy management affects soil redox potential, leading to the formation of distinct layers characterizing Fe/Mn distribution /redistribution (Roy et al. 2003) and nutrient transformations influence soil microorganisms and soil nitrogen cycling (Kikuchi et al. 2007; Xin et al. 2014). Manganese toxicity to microorganisms has been proposed (He et al. 2005; Xin et al. 2015), and MnO_2 may also act as electron acceptor, oxidizing NH_3/NH_4^+ to N_2 directly under anaerobic conditions, which is thermodynamically favorable, especially in acid soils (Luther et al. 1997). Therefore, we hypothesized that MnO_2 may play an important role in nitrification and denitrification in rice-based ecosystems with variable water management, since it has both environmental and economic concerns.

Materials and Methods

Paddy soils were collected from Purple Soil Ecology Experimental Station of Southwest University, Chongqing, China (30° 26’ N, 106° 26’ E). Subsamples were prepared by amendment with 0% (unamended control) or 3% birnessite by weight. Soil moisture content of each sample was adjusted with deionized water to form three treatments: 50%, 100%, and 200% Water-holding capacity (WHC) moisture contents. After pre-incubation for 7 days, each spiked with 120 mg N kg^{-1} $(NH_4)_2SO_4$ and At the intervals of 0, 1, 3, 7, and 10 days, subsamples were taken and analyzed for NH_4-N, NO_3-N, pH, Eh and N_2O fluxes. NO_3^--N concentration were modeled with a first-order reaction kinetic model. Data were subjected to one-way ANOVA and mean values were separated using Tukey’s test and Duncan’s multiple range test at $P<0.05$. All statistical analyses were performed by SPSS statistical package.

Results

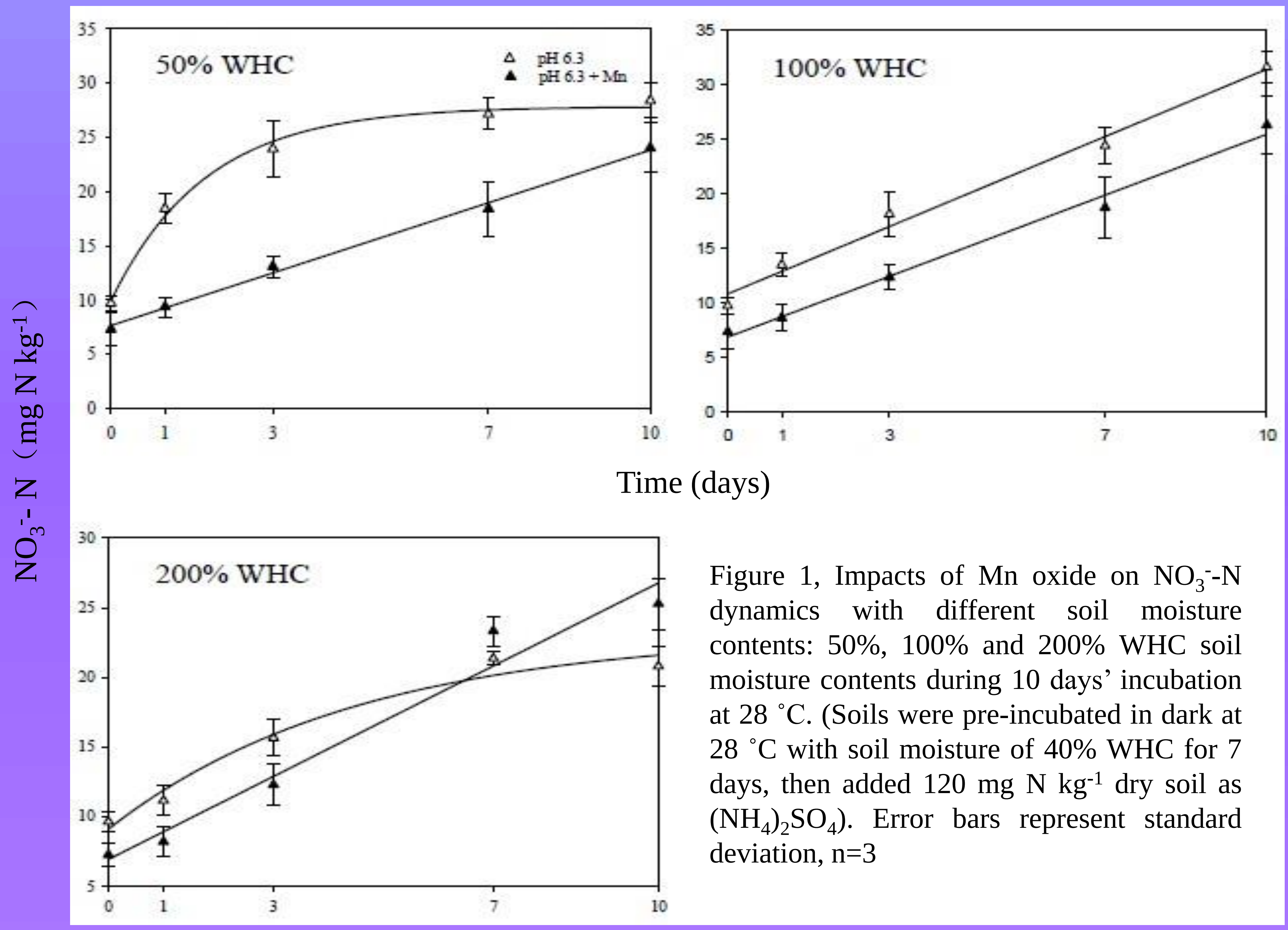
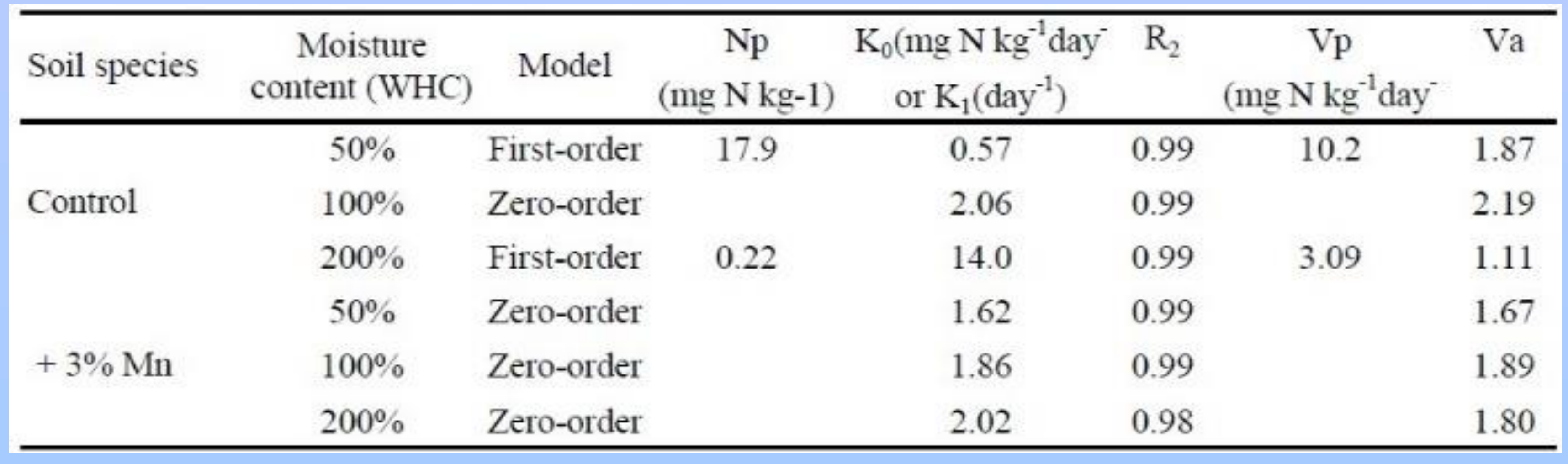


Figure 1, Impacts of Mn oxide on NO_3^--N dynamics with different soil moisture contents: 50%, 100% and 200% WHC soil moisture contents during 10 days’ incubation at 28 ˚C. (Soils were pre-incubated in dark at 28 ˚C with soil moisture of 40% WHC for 7 days, then added 120 mg N kg^{-1} dry soil as $(NH_4)_2SO_4$). Error bars represent standard deviation, n=3



Soil species	Moisture content (WHC)	Model	Np (mg N kg-1)	K_0(mg N $kg^{-1}day^{-}$ or $K_1(day^{-1})$	R_2	Vp (mg N $kg^{-1}day^{-}$	Va
Control	50%	First-order	17.9	0.57	0.99	10.2	1.87
	100%	Zero-order		2.06	0.99		2.19
	200%	First-order	0.22	14.0	0.99	3.09	1.11
+ 3% Mn	50%	Zero-order		1.62	0.99		1.67
	100%	Zero-order		1.86	0.99		1.89
	200%	Zero-order		2.02	0.98		1.80

Table 1. Parameters of zero or first-order kinetics fitting NO_3^--N accumulation during the 10 days’ incubation in a subtropical rice soil with variable water regimes. Np was potential nitrification; k0 or k1 was the rate constant of zero or first–order kinetics model; Vp was potential nitrification rate calculated from first-order kinetics as Vp = k1* Np; Va was average net nitrification rate.

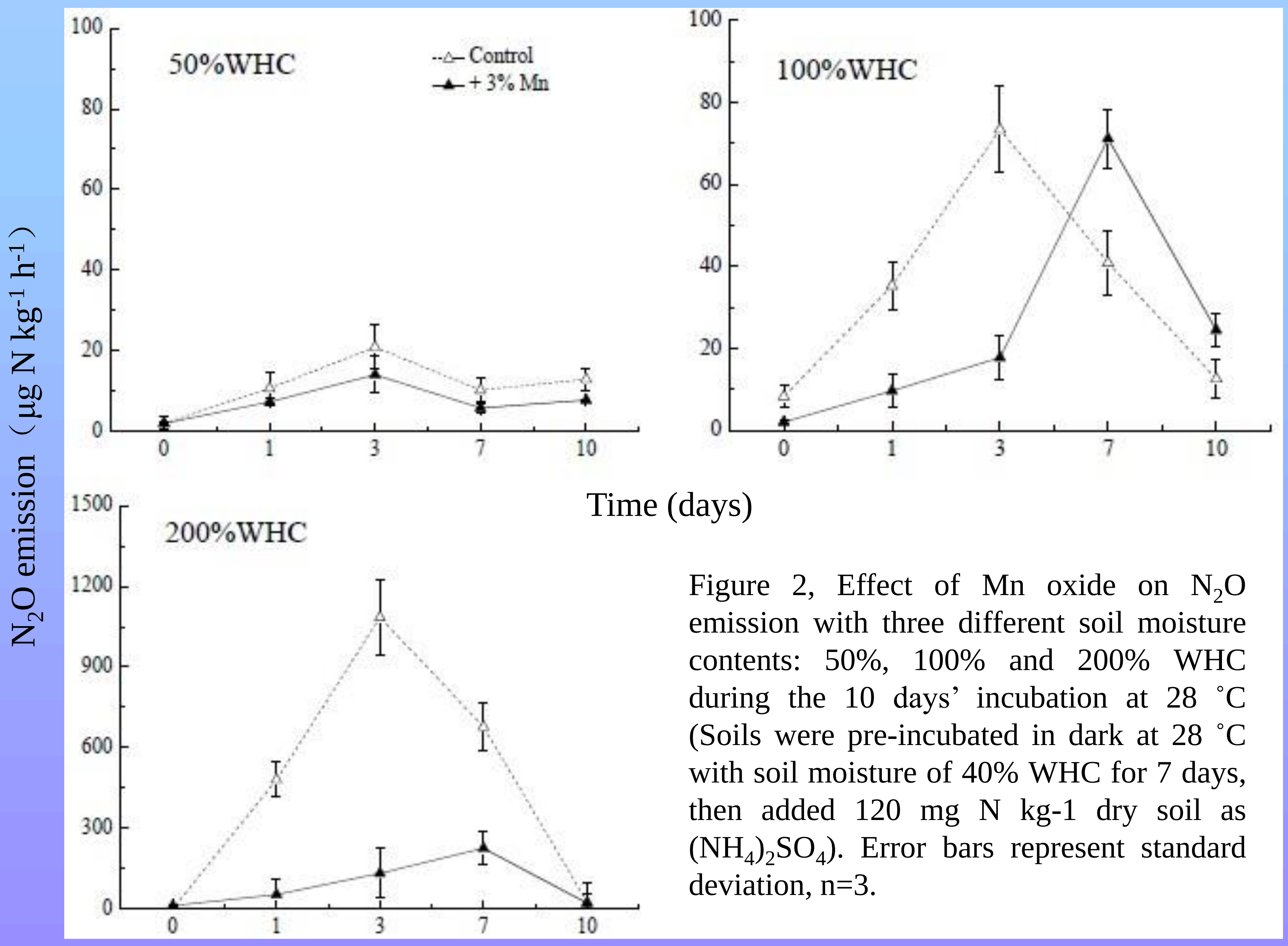


Figure 2, Effect of Mn oxide on N_2O emission with three different soil moisture contents: 50%, 100% and 200% WHC during the 10 days’ incubation at 28 ˚C (Soils were pre-incubated in dark at 28 ˚C with soil moisture of 40% WHC for 7 days, then added 120 mg N kg-1 dry soil as $(NH_4)_2SO_4$). Error bars represent standard deviation, n=3.

Discussion

- Simulated results from nitrification dynamics indicated that Mn addition changed the pattern of nitrification from first-order to zero-order model (Table 1). This indicated that the substrate for nitrification (NH_3) was sufficient relative to the oxidizing capacity of the ammonia oxidizers, and nitrification rates were limited by ammonia oxidizers rather than the substrate (NH_3) supply. Possible mechanisms may include Mn toxicity to nitrifying microorganisms, such as AOB and AOA (Xin et al. 2015).
- Nitrification was retarded by MnO_2 under aerobic condition while significantly increased in the anaerobic treatment. The stimulation of nitrification by MnO_2 in the anaerobic condition may imply that MnO_2 plays an essential role as electron acceptor when O_2 is depleted.
- The N_2O emission rate decreased while NO_3^--N accumulation increased significantly after MnO_2 addition at 200% WHC (Figures 1 and 2), indicating that denitrification was depressed or inhibited by Mn oxide under anaerobic conditions. Possible mechanisms involved in the depression of denitrification by Mn oxide may include competition as electron acceptors between NO_3^- and MnO_2 when O_2 was depleted.

Acknowledgements:

Synergy in Science: Partnering for Solutions
ASA•CSSA•SSSA
2015 MEETING
November 15-18
Minneapolis, MN

This research was, in part, supported by the Natural Science Foundation of China (No. 41271267) , the Programs Foundation of Ministry of Science & Technology, China (2013BAJ11B03), a scholarship from the China Scholarship Council awarded to Xiaoping Xin and the University of Florida.

Conclusion

Manganese oxide affects nitrification and N_2O emissions in a subtropical rice soil with variable water regimes, implying that manganese oxides may play an important role in the variation of nitrification in acidic soils.