Geoderma 325 (2018) 1–8

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Lime application lowers the global warming potential of a double rice cropping system

Yu Jiang[a,b,c,1], Ping Liao[e,1], Natasja van Gestel[d], Yanni Sun[e], Yongjun Zeng[e], Shan Huang[e,*], Weijian Zhang[a], Kees Jan van Groenigen[b]

[a] Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Ministry of Agriculture, Beijing 100081, China
[b] Geography, College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4 RJ, UK
[c] Institute of Applied Ecology, Nanjing Agricultural University, Nanjing 210095, China
[d] Climate Science Center, Texas Tech University, Lubbock, TX, USA
[e] Ministry of Education and Jiangxi Key Laboratory of Crop Physiology, Ecology and Genetic Breeding, Jiangxi Agricultural University, Nanchang 330045, China

ARTICLE INFO

Handling Editor: M. Vepraskas

Keywords:
Greenhouse gas
Soil acidification
Climate change
Food security
Soil carbon

ABSTRACT

Liming is a common practice to alleviate soil acidification in agricultural systems worldwide. Because liming affects soil microbial activity and soil carbon (C) input rates, it can affect soil greenhouse gas (GHG) emissions as well. However, little is known about the effect of liming on GHG emissions from rice agriculture, one of the main sources of anthropogenic methane (CH_4). Here, we report on the first experiment to measure the effect of liming on GHG emissions from rice paddy fields. We studied a double rice cropping system in an acid paddy for two years and measured the impacts of liming on GHG emissions and rice growth with or without straw incorporation. We found that liming reduced CH_4 emissions in the early rice season, but it did not affect nitrous oxide (N_2O) emissions. Over the two-year study, lime application reduced total CH_4 emissions by 12.5% and 15.4% in plots without and with straw incorporation, respectively. Lime application significantly enhanced rice aboveground biomass, while reducing the area- and yield-scaled global warming potential of CH_4 and N_2O emissions. Lime application stimulated soil respiration during the fallow season and reduced the abundance of methanogens during the early rice growing season. Together, these results suggest that liming reduces CH_4 emissions by promoting the decomposition of organic matter during the fallow season, thereby reducing C availability for methanogens. We conclude that in the short term, liming is an effective practice to reduce greenhouse gas emissions from acidic paddy soils.

1. Introduction

Rice paddies constitute a major source of greenhouse gas (GHG) emissions and account for approximately 20% of global agricultural methane (CH_4) emissions (IPCC, 2013) and 8–11% of China's cropland nitrous oxide (N_2O) emissions (Zou et al., 2009). At the same time, rice is a staple food for about half of the world's population and global demand for rice is expected to increase by 28% in 2050 (Alexandratos and Bruinsma, 2012). Yet, rice yield improvements have recently stagnated in many rice cropping areas (Ray et al., 2012; Grassini et al., 2013). Soil acidity is a main factor limiting rice yield improvement, particularly in subtropical China because of excess N input and the inherent low soil pH (Guo et al., 2010; Miao et al., 2011). Liming is a common management practice for ameliorating soil acidity and increase crop yields, and is commonly applied in rice agriculture (Kirk et al., 2010; Fageria and Nascente, 2014; Holland et al., 2018). However, the effect of lime application on CH_4 and N_2O emissions from rice paddies remains unclear.

Methane is produced by methanogens under anaerobic conditions and is affected by soil pH and C availability (Le Mer and Roger, 2001; Conrad, 2007). Lime application can increase soil pH, which may provide more favorable conditions for CH_4 production (Kunhikrishnan et al., 2016). For instance, Murakami et al. (2005) showed that lime application increased soil pH and then stimulated CH_4 production in peat soils. Liming can also influence soil C availability through improving soil structure, increasing plant productivity, and stimulating soil microbial activity (Paradelo et al., 2015). On the other hand, by increasing soil pH, liming may also stimulate CH_4 oxidation rates (Hilger et al., 2000; Knief et al., 2003). Barton et al. (2014) found that liming increased CH_4 uptake from wheat cropping systems. Thus,

* Corresponding author.
E-mail address: ecohs@126.com (S. Huang).
[1] The two authors contributed equally to this work.

https://doi.org/10.1016/j.geoderma.2018.03.034
Received 16 December 2017; Received in revised form 17 March 2018; Accepted 25 March 2018

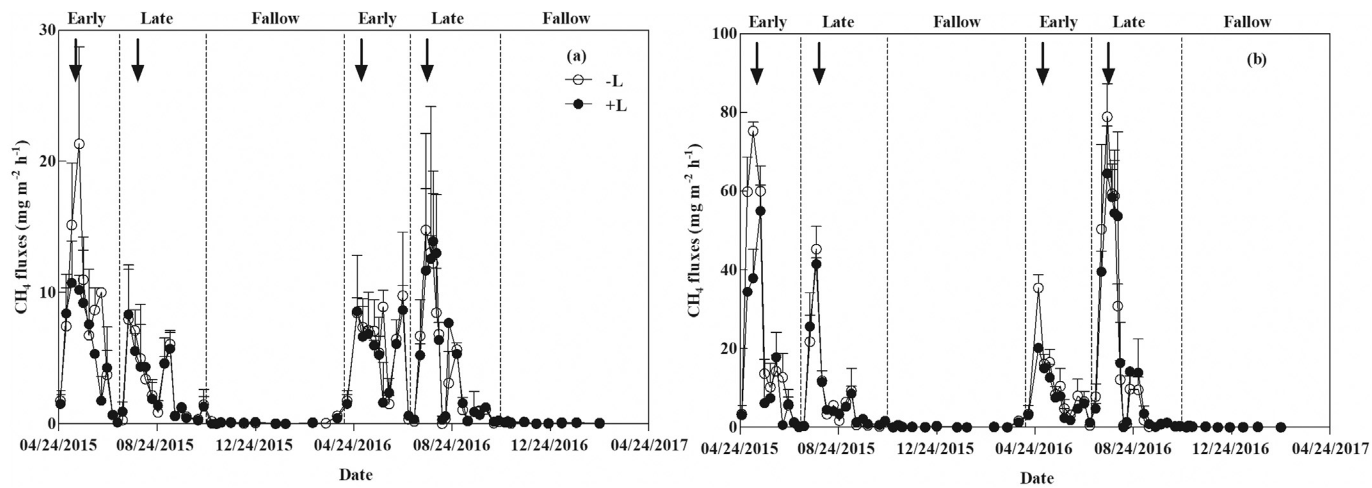

Fig. 1. Effects of liming (−L and +L) on CH_4 fluxes in the plots without (a) and with straw incorporation (b). The arrows indicate the tillering stages. Error bars represent the standard deviation of the mean.

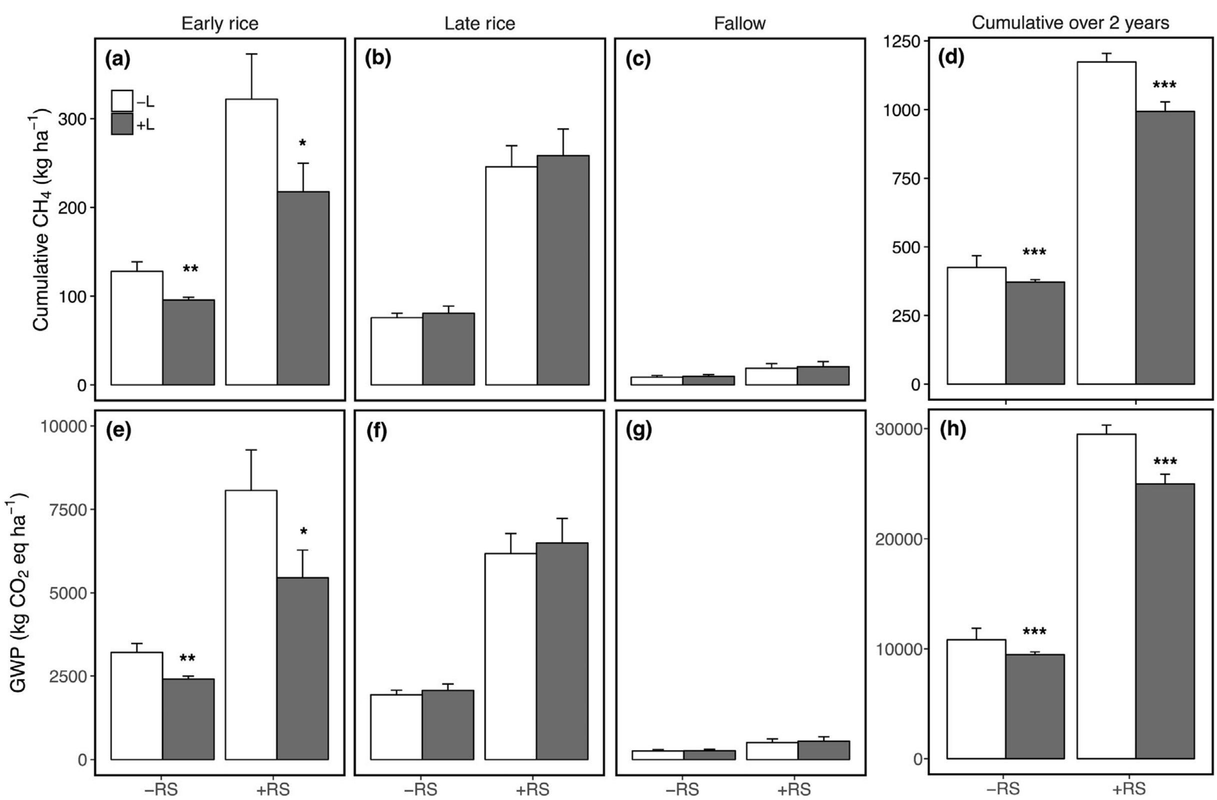

Fig. 2. Seasonal cumulative emissions of CH_4 (a-c) and area-scaled global warming potential (GWP; e–g) during early rice, late rice and fallow seasons in response to liming (−L and +L) and rice straw incorporation (−RS and +RS). Results were averaged across two years because there were no significant 4-way interactions (straw × liming × crop × year). Cumulative CH_4 emissions (d) and GWP (h) for the entire 2-year study period are shown on the right. Error bars represent the standard deviation of the mean. Asterisks (*) indicate significant differences between liming treatments within the straw treatments at $P \le 0.001$ (***), $0.001 < P \le 0.01$ (**) or $0.01 < P \le 0.05$ (*).

evidence suggests that liming can influence both the production, oxidation, and emission of CH_4. However, no experiments have so far assessed the effect of liming on CH_4 emissions from rice paddies.

Soil N_2O is produced mainly through nitrification and denitrification processes (Bouwman, 1998; Zhu et al., 2013). Liming can affect soil nitrification and denitrification rates, thereby influencing N_2O emissions (Kunhikrishnan et al., 2016). For instance, Barton et al. (2013) found that lime application reduced N_2O emission from nitrification. Qu et al. (2014) showed that liming reduced N_2O emissions due to the pH-control of the $N_2O/(N_2O + N_2)$ production ratio. Liming can stimulate plant N uptake (Chang and Sung, 2004), and thereby potentially reduce N availability for denitrification. However, studies measuring the effect of liming on N_2O emissions focused on upland soils; to the best of our knowledge, no study has investigated the impact of liming on N_2O emissions from rice paddy fields.

Besides liming, straw incorporation is another widely applied agricultural practice. Straw incorporation can improve soil fertility, soil organic carbon (SOC) sequestration and rice yield (Huang et al., 2013; Liu et al., 2014). Straw incorporation is applied in approximately 38% of China's rice paddy area, and this percentage is projected to increase