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ORIGINAL ARTICLE

Effect on greenhouse gas balance of converting rice paddies to vegetable production

Lei Wu[1] · Xian Wu[1] · Ronggui Hu[1]

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Abstract Rice paddies are increasingly being converted to vegetable production due to economic benefits related, in part, to changes in demand during recent decades. Here, we implemented a parallel field experiment to simultaneously measure annual emissions of CH_4 and N_2O, and soil organic carbon (SOC) stock changes, in rice paddies (RP), rice paddy–converted conventional vegetable fields (CV), and rice paddy–converted greenhouse vegetable fields (GV). Changing from rice to vegetable production reduced CH_4 emissions by nearly 100%, and also triggered substantial N_2O emissions. Furthermore, annual N_2O emissions from GV significantly exceeded those from CV due to lower soil pH and higher soil temperature. Marginal SOC losses occurred after one year of cultivation of RP, CV, and GV, contributing an important share (3.4%, 32.2%, and 10.3%, respectively) of the overall global warming potential (GWP) balance. The decline in CH_4 emissions outweighed the increased N_2O emissions and SOC losses in CV and GV, leading to a 13%–30% reduction in annual GWP as compared to RP. These results suggest that large-scale expansion of vegetable production at the expense of rice paddies is beneficial for mitigating climate change in terms of the overall GWP.

Keywords Greenhouse gas balance · Land management change · CH_4 · N_2O · Soil organic carbon

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✉ Ronggui Hu

Lei Wu
wuleies@163.com

[1] College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China

1 Introduction

Over the last few decades, because of water scarcity, economic benefits, and changes in diets, rice paddies have been increasingly subject to shifts in the land-use regime, such as conversion of rice cropping systems to upland crop cultivation like maize, fruits, and vegetables (Sun et al. 2011). Conversion of rice to vegetable cultivation significantly reduces CH_4 emission, but can induce increases in N_2O emissions as well as soil organic carbon (SOC) losses due to aerobic conditions, which facilitate N transformation and SOC mineralization (Weller et al. 2016). It remains unclear whether the positive effects of CH_4 mitigation can be negated by the corresponding increases in N_2O emissions and SOC losses. In this study, we evaluated the short-term effects of land-management change from rice to vegetable production on annual CH_4 and N_2O emissions, SOC stocks, and the resulting overall global warming potential (GWP).

2 Materials and methods

The selected experimental plots had been cultivated with double rice cropping for at least 100 years prior to 2013 in Hunan Province, China. Portions of these rice paddy fields were randomly assigned to be converted to vegetable cultivation—either in fields or greenhouses—after late rice harvest in October 2013. The experiment began in October 2014 and lasted over a year with three treatments: rice paddy (RP), rice paddy-converted conventional vegetable (CV), and rice paddy-converted greenhouse vegetable (GV) plots in a randomized block design with three replicates of each treatment. Field management followed local conventional practices.

CH_4 and N_2O fluxes were measured simultaneously in RP, CV, and GV plots using the static opaque chamber technique from October 2014 to October 2015. To compare the annual full greenhouse gas (GHG) balances of different treatments, the overall GWP for each treatment was calculated using the CO_2-equivalent (CO_2-eq) of 28 for CH_4 and 265 for N_2O relative to CO_2 over a 100-year time horizon (IPCC 2013). Changes in SOC stocks for each treatment were calculated as the difference between the initial SOC stocks (measured in October 2014) and those measured after a full year, and were included as direct CO_2-eq in the overall GWP balance. Concurrent with CH_4 and N_2O flux measurements, topsoil temperature, moisture, pH, mineral N (NH_4^+ and NO_3^-), and dissolved organic carbon (DOC) were measured.

3 Results and discussion

3.1 Effect of land-management change on CH_4 and N_2O emissions

The RP plots emitted 720.9 kg CH_4-C ha^{-1} yr^{-1}, exceeding values reported in previous studies (Wang et al. 2016; Zhang et al. 2016), which we attribute to an extended flooding period and to high soil temperature—both favorable conditions for CH_4 production—and to the double rice cropping system at our study site versus single rice cropping in other regions (Feng et al. 2013). However, land-management change from rice to vegetable cultivation decreased CH_4 emissions by almost 100%, largely due to reduced soil moisture and improved soil aeration with higher redox potential, hence inhibiting CH_4 production while enhancing CH_4 oxidation.

N_2O fluxes were negligible in RP plots due to prolonged flooding limiting soil oxygen availability and nitrification potential, thus suppressing the supply of NO_3^- for subsequent denitrification, limiting N_2O production while promoting N_2O uptake. Draining rice paddies for vegetable cultivation triggered substantial N_2O emissions: increased oxygen availability promoted nitrification and accelerated soil organic N mineralization and related N_2O production. Given the high levels of soil moisture (water-filled pore space, WFPS $> 60\%$) and soil NO_3^- in both CV and GV plots, the positive relationship between N_2O fluxes and WFPS implied that denitrification was the dominant process for N_2O production. Annual N_2O GV emissions significantly exceeded those from CV plots, which we attribute primarily to higher soil moisture and temperature, and lower pH in GV favoring N_2O production (Mei et al. 2011). Annual N_2O emissions from our CV and GV plots were much higher than those reported for other vegetable fields (Yan et al. 2014; Yao et al. 2015), presumably due to legacy effects of rice crop cultivation including high content of soil organic N, influencing N_2O production.

3.2 Effect of land management change on GWP considering SOC stock changes

Land management change from RP to CV and GV dramatically decreased CH_4 emissions, outweighing the increase in N_2O emissions and losses of SOC stocks and leading to notable reductions in total GHG emissions. These results suggest that replacing paddy fields with vegetable cultivation could significantly mitigate the integrative greenhouse effect.

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