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N_2O and CO_2 emissions, nitrogen use efficiency under biogas slurry irrigation: A field study of two consecutive wheat-maize rotation cycles in the North China Plain

Gaofei Yin[a,b], Xiaofei Wang[c], Huiying Du[a,b], Shizhou Shen[a,b], Canran Liu[d], Keqiang Zhang[a,b,*], Wenchao Li[e,**]

[a] Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin, 300191, China
[b] Dali Experimental Station of Agro-Environmental Protection Institute, Ministry of Agriculture, Yunnan, 671004, China
[c] Henan Academy of Agricultural Sciences, Zhengzhou, 450002, China
[d] Department of Environment, Land, Water and Planning, Arthur Rylah Institute for Environmental Research, Heidelberg, VIC, 3084, Australia
[e] Key Laboratory of Nonpoint Pollution Control, Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China

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ABSTRACT

Reuse of biogas slurry (BGS) could reduce fertilizer application rate because this material is an alternative source of nutrients and irrigation that could replace some of applied fertilizer. However, the environmental impacts of BGS irrigation, such as greenhouse gas emissions (GHG) are poorly understood. We investigated the global warming potential (GWP) and greenhouse gas intensity (GHGI) of BGS irrigation by quantifying the nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions under different BGS irrigation rates in a two-year wheat-maize rotation field in the North China Plain. We found BGS irrigation did not change the patterns and fluxes of CO_2 and N_2O emission during the entire wheat-maize cropping cycle. In addition, there were no significant difference between BGS treatments (BSL, BSM, and BSH) and conventional fertilizer treatment (CF) in GWP. Further, no significant difference occurred in GHGI between BSM (33% BGS and 67% groundwater were mixed and irrigated during the wintering period and joining stage of wheat and after maize sowing, 315 kg·N·hm^{-1}), BSH (50% BGS and 50% groundwater were mixed and irrigated during the wintering period and joining stage of wheat and after maize sowing, 477 kg·N·hm^{-1}) and CF (conventional NPK fertilizer, 420 kg·N·ha^{-1}), despite a higher value BSL (33% BGS and 67% groundwater were mixed and irrigated during the wintering period of wheat and after maize sowing, 210 kg·N·hm^{-1}).The BSL and BSM treatments significantly increased the nitrogen use efficiency (NUE) compared to the CF treatment (11.3% for BSL and 15.3% for BSM). Despite the lower NUE in the BSH treatment relative to CF, it was not statistically significant. Therefore, BGS reuse can increase NUE and does not cause environmental impacts. According to the results of GHGI and NUE, it can be concluded that BSM should be recommended as an improved recycling management practice for the wheat-maize rotation systems.

1. Introduction

Agriculture is a major source of greenhouse gas emissions, with 5–20% of CO_2 and 80–90% of N_2O emissions in the atmosphere arising from agriculture in China (Luo et al., 2017). The North China Plain (NCP) occupies an agricultural area of approximately 300,000 km^2, accounting for 23% of the total cropland area in China (Ding et al., 2007). The winter wheat-summer maize rotation is the most popular double-cropping system in this area, and it produces 20.9% of wheat and 35.6% of maize yields in China (NBSPRC, 2016). In the North China Plain, maintaining and increasing crop productivity requires substantial irrigation (90–690 mm year^{-1}, Wang et al., 2008) and chemical fertilizer application (500–700 kg N ha^{-1} year^{-1}, Ju et al., 2009) which far exceed the recommended rates (e.g. 127–350 kg N ha year^{-1}, He et al., 2009; Wang et al., 2010). Consequently, excessive fertilizer stimulates CO_2 and N_2O emissions (Ding et al., 2007; Li et al., 2018). Recycling biogas slurry (BGS), a source of both nutrient and irrigation water, could replace some of applied fertilizer while

* Corresponding author at: Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin, 300191, China.
** Corresponding author.
E-mail addresses: keqiangzhang68@163.com (K. Zhang), dachao279@126.com (W. Li).

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maintaining food productivity by returning nutrients and water to the soil for plant growth.

The reuse of slurry from manures is a cost effective method that provides essential nutrients, such as nitrogen, phosphorus, and potassium for plant growth (Kotzerke et al., 2008). During fermentation, the NH_4^+ content of the biogas slurry increases while the C/N ratio and odor decrease in comparison to animal manures used as sources of organic material (Terhoeven-Urselmans et al., 2009). Consequently, higher plant yields have been observed in some cases after biogas slurry application due to the high content of NH_4^+ content of biogas slurry (Möller et al., 2008). However, excessive application of this slurry may lead to water pollution via runoff and leaching and to gaseous emissions of nitrous oxide and carbon dioxide (Zhao et al., 2006; Abubaker et al., 2015; Heintze et al., 2017).

However, the environmental impacts of BGS irrigation are poorly understood. Previous studies mostly focused on the influence of synthetic fertilizer use on emissions of CO_2 and N_2O from agricultural soils. Few studies have addressed the impacts of BGS irrigation on CO_2 and N_2O emissions from wheat-maize rotations. Additionally, current research mostly focused on the effect of BGS use on crop growth and water use efficiency (Bhattarai et al., 2006; Chen et al., 2011; Niu et al., 2013). Only a few studies have addressed the comprehensive influence of BGS on atmospheric quality, soil properties and nitrogen use efficiency (NUE) (Niu et al., 2013; Shah et al., 2016; Yang et al., 2018).

Here we investigated the global warming potential (GWP) and greenhouse gas intensity (GHGI) of BGS irrigation by quantifying the N_2O and CO_2 emissions under different BGS irrigation rates in a two-year wheat-maize rotation field trial in the North China Plain. In addition, the NUE was also evaluated. The primary objective of this study was to explore the impacts of BGS irrigation on GHG emissions and NUE. Specifically, three objectives are defined: (i) to identify the critical factors influencing greenhouse gases; (ii) to explore the NUE under BGS conditions; and (iii) to investigate the GWP and GHGI of BGS and its environmental impacts.

2. Materials and methods

2.1. Site and soil description

The study was conducted in a winter *Triticum aestivum*-summer *Zea mays* rotation system in Liangjiaying County (38°56′N, 115°32′E), Hebei Province, China, from 2014–2016. Winter wheat-summer maize rotation is the most popular double-cropping system in this area in conjunction with livestock and poultry enterprises. The study site has a typical sub-humid, temperate, continental monsoonal climate, with an average annual precipitation of 519 mm and mean annual temperature of 12.3 °C. The daily mean air temperature and total precipitation at the experimental site during the wheat-maize cropping system are shown in Fig. 1. Approximately 80% of the total annual precipitation occurs from July to September. The soil properties (0–20 cm) were: Bulk density, 1.3 g cm^{-3}; soil organic matter, 9.4 g kg^{-1}; total N, 1.4 g kg^{-1}; nitrate-*N*, 13.2 mg kg^{-1}, ammonium-*N*, 1.0 mg kg^{-1}; total-P, 0.7 g kg^{-1}; pH, 7.7.

2.2. Field experiments

The agricultural field was divided into five treatments (Table 1): (1) CK: a control treatment with no fertilizer and no BGS irrigation; (2) CF: Nitrogen fertilizer was applied in the form of urea (46% N), P fertilizer as superphosphate (P_2O_5 16%), and K fertilizer as potassium chloride (K_2O 57%), and the amount of N was 420 kg ha^{-1}, with water irrigation; (3) BSL: 33% BGS and 67% groundwater were mixed and applied as irrigation during the wintering period for wheat and after maize sowing, and the amount of N was 210 kg ha^{-1}, with no chemical fertilizer added; (4) BSM: 33% BGS and 67% groundwater were mixed and applied as irrigation during the wintering period and joining stage of wheat and after maize sowing, the amount of N being 315 kg ha^{-1}, and no chemical fertilizer was added; and (5) BSH: 50% BGS and 50% groundwater were mixed and applied as irrigation during the wintering period and joining stage of wheat and after maize sowing, and the amount of N being 477 kg ha^{-1}, with no chemical fertilizer added. The experimental layout was a randomized complete block design replicated three times with plots 8.5 m long and 6 m wide. The biogas slurry mixtures were applied using a PVC plastic pipe with a 10 cm diameter; the application rate was recorded using a pipeline ultrasonic flowmeter (UF10, Tianjin Jutradar technology and trading Co., Ltd) which was used to control the irrigation quantity, and the error was less than 1%.

Wheat (Jimai22) was planted on October 6, 2014, and harvested on June 15, 2015 during cycle 1. For cycle 2, the planting and harvesting dates were October 7, 2015 and June 15, 2016, respectively. Maize (zhengdan958) was planted on June 18, 2015 and harvested on September 30, 2015 during cycle 1. For cycle 2, planting and harvest dates were June 18, 2015 and September 30, 2016, respectively. Herbicide was applied to control weeds. The grain yields were measured for each plot and grain samples were dried at 65 °C until reaching a constant weight to determining the dry matter yields.

During the wheat season, BGS was applied four times at a 30 mm depth each time, on December 5th, 2014; April 4th, 2015; May 5th, 2015; May 26th; 2015 for cycle 1 and December 3rd, 2015; April 7th, 2016; May 5th, 2016; May 25th, 2016 for cycle 2. During the maize season, the soil was irrigated once at 30 mm on June 15th, 2015 during cycle 1 and June 15th, 2016 for cycle 2.

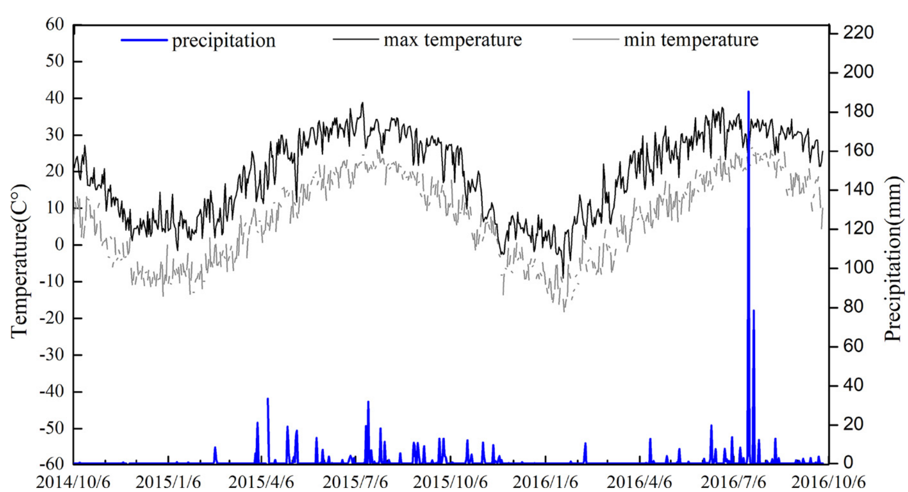

Fig. 1. Environmental variables during.2014–2016.