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Effects of fertilizer and irrigation management on nitrous oxide emission from cotton fields in an extremely arid region of northwestern China

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ABSTRACT

Nitrogen application as synthetic fertilizer and/or animal manure and method of irrigation are critical management practices affecting crop production and nitrous oxide (N_2O) emission in irrigated agriculture systems. A field experiment was conducted in 2015 and 2016 to compare the effects of conventional urea (Urea), animal manure (Manure) and a 50/50 mix of urea and manure (U + M) on N_2O emission from flood- or drip-irrigated cotton (*Gossypium hirsutum* L.) grown on a sandy soil in arid region of northwestern China. Results showed that Manure increased cumulative N_2O emission (ΣN_2O), applied available N-scaled emission factor (EF) and yield-scaled emission intensity (EI) by 30–188% compared with Urea and U + M, under both irrigation methods. The ΣN_2O and EF were not affected by irrigation method in 2015, but were 18–25% greater in the drip- than flood-irrigation in 2016. Cotton yield and N uptake were generally increased by fertilizer or manure additions compared to the unfertilized control, but there were no significant differences between the three fertilized treatments. The overall N_2O emission and EF at the study site ranged between 72–506 g N_2O-N ha^{-1} and 0.04-0.15%, respectively, being generally lower than those of other climate zones, probably due to the low available soil moisture and low soil organic carbon which restricted N_2O production. Greater N_2O emission with manure application was mainly attributed to the increased rates of nitrification and denitrification through the manure's increased supply of carbon for associated microbes. These results suggest a potential risk of manure application to increase N_2O emission for irrigated crop production in soils with low soil organic matter and under dry climate. Further studies are needed for understanding of the linkage between manure-induced N_2O emission and activities of associated microbes.

1. Introduction

Nitrous oxide (N_2O) is one of the most important greenhouse gases in the atmosphere, contributing to both global warming and the destruction of stratospheric ozone (Ravishankara et al., 2009). Net anthropogenic N_2O emissions are estimated at 5.3 Tg N_2O-N yr^{-1}, of which, 66% is derived from agriculture, primarily due to nitrogen (N) addition through fertilizer and manure application (Davidson and Kanter, 2014). Moreover, irrigation management is also a key factor influencing N_2O emission from cropland (Sanchez-Martin et al., 2008). Therefore, combinations of irrigation and N management practices are of great importance to mitigate N_2O emissions from agricultural system.

Nitrous oxide is produced through microbiological processes of nitrification and denitrification, which are controlled by soil temperature, moisture, and availability of mineral N and organic carbon (C) (Beauchamp, 1997). Among these factors, soil moisture content is the key factor affecting N_2O emission as it determines the activities of microbes and nutrient availability (Sanchez-Martin et al., 2008). Drip irrigation is an efficient water-saving strategy widely used for crop production in arid regions (Vázquez et al., 2006). Method of irrigation can exert significant impact on N_2O emission because of its effect on the temporal and spatial distribution of water filled pore space (WFPS) and

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consequently on the biological processes of nitrification and denitrification. Several studies have reported that drip irrigation reduced N_2O emission from crop fields, compared with conventional flood irrigation (Sanchez-Martin et al., 2008; Li et al., 2013; Bronson et al., 2018). Lower WFPS under drip- than flood- irrigation method was found to reduce the activity of nitrifying bacteria and thus the rate of nitrification (Jha et al., 1996). In addition, under drip irrigation, distributions of soil WFPS and mineral N can limit N_2O emission as NO_3^- accumulates in dry areas where WFPS are generally below the threshold for nitrification and NH_4^+ accumulates in wet areas with WFPS suitable for the reduction of N_2O to N_2 (Guardia et al., 2017). In contrast, Guo et al. (2016) reported greater N_2O emission from drip- than flood- irrigation because complete denitrification reduced N_2O emission under flood irrigation. Therefore, more field measurements are required to clarify the effect of irrigation method on N_2O emissions from cropland, especially in the extremely arid regions where nearly 90% of water requirement of crops is provided through irrigation.

Synthetic fertilizers and organic manure are important sources of N_2O emission from soils (Mosier et al., 1998). Nitrogen source influences the relative importance of nitrification and denitrification through affecting soil factors such as the form of available N and C (Velthof et al., 2003). Previous studies comparing N_2O emissions from organic manure and synthetic fertilizers have produced inconsistent results. Several studies reported that manure application increased N_2O production by denitrification through providing C substrate for denitrifiers (Hayakawa et al., 2009; Forte et al., 2017; Ju et al., 2011). In contrast, other studies reported that N_2O emission from manure application were less than from synthetic fertilizers, because manure stimulated complete denitrification to N_2 (Ball et al., 2004; Meijide et al., 2007; Tao et al., 2018). In addition, some studies found no differences in N_2O emission between manure and synthetic N fertilizer applications (Meng et al., 2005; Vallejo et al., 2006). Based on a meta-analysis of 846 field measurements, Bouwman et al. (2002) found applied N-scaled N_2O emission factor (EF) was similar for synthetic fertilizer and animal manure, being 1.0% and 0.8%, respectively. In contrast, also based on a global meta-analysis, Zhou et al. (2017) reported that manure application increased N_2O emission by 32.7% compared to synthetic fertilizers. These inconsistent results reflect the uncertainty of N source effect on N_2O emissions, which is complicated by multiple factors such as climate, soil and crop management practices.

Cotton is the main cash crop of Xinjiang autonomous province in northwestern China. According to the National Bureau of Statistics of China, (2016), the planted area of cotton in Xinjiang was 1.8×10^6 ha, accounting for 54% of total cotton planting area in China. Xinjiang is located in an arid and semi-arid climate region, where water is the key limiting factor for cotton production. Drip irrigation is widely used in Xinjiang cotton production due to the benefits of reduced evaporation and increased water use efficiency. In this system, soluble synthetic N sources, usually urea, are often split-applied with irrigation water (fertigation) over the growing season. Animal manures are also often applied for cotton production in this area due to nearby production of livestock. Several studies have investigated the effect of manure application on N_2O emissions from the drip-irrigated cotton production in this area but revealed inconsistent results. For example, Lv et al. (2014) reported greater N_2O emissions from application of manure plus synthetic fertilizers, compared with synthetic fertilizers only. In contrast, Tao et al. (2018) recently reported that addition of cattle manure to drip-irrigated cotton reduced N_2O emissions compared to synthetic fertilizer. It remains unclear whether the different results between studies were related to soil factors such as soil texture or management factors such as type of manure. To our knowledge, no study has investigated the coupling effect of irrigation type and N source on N_2O emissions from cotton production in arid regions.

The objective of this study was to investigate the effect of manure versus synthetic fertilizer application on N_2O emissions from cotton under both drip- and flood- irrigation methods in an extremely arid region in northwestern China. We hypothesized that manure application would increase N_2O emission through providing C supply for associated N_2O producing microbes.

2. Materials and methods

2.1. Site description and soil properties

Field experiments were conducted over two growing seasons (2015 and 2016) at Cele Research Station (37°01′06″N, 80°43′48″E) of Xinjiang Institute of Geography and Ecology, Chinese Academy of Sciences. The research station is located at the southern edge of Taklimakan Desert with a typical arid continental climate. This area has a mean annual precipitation of only 42.5 mm and evaporation of 2956 mm on the 30-year (1981–2010) scale. Average annual air temperature is 12.7 °C, ranging from 42 °C in summer to −24 °C in winter. The soils are classified as Aridisols in the USDA ST system (United States Department of Agriculture (USDA), 1999). The groundwater depth is approximately 14.0 m with salinity around 1.8 g L^{-1} and pH of 7.7. Soil texture is fine sand with sand/silt/clay of 900/40/60 g kg^{-1} for 0–20 cm, 920/35/45 g kg^{-1} for 20–40 cm, 912/37/51 g kg^{-1} for 40–60 cm, and 907/38/54 g kg^{-1} for 60–100 cm, respectively. Bulk density increases slightly with soil depth, being 1.46, 1.51, 1.54, 1.55 g cm^{-3} for 0–20, 20–40, 40–60, 60–100 cm, respectively. Prior to the study, soil (0–20 cm) at the trial site had the following concentrations: organic matter 6.9 g kg^{-1}, total Kjeldahl N 0.34 g kg^{-1}, NO_3^--N 25.7 mg kg^{-1}, NH_4^+-N 1.7 mg kg^{-1}, 0.5 M $NaHCO_3$ extractable phosphorus (P) 14.6 mg kg^{-1}, 1.0 M ammonium acetate extractable potassium (K) 153 mg kg^{-1}, pH_{H2O} 8.0, and electrical conductivity (EC) 144.4 μS cm^{-1}. During the experiment, daily air temperature and precipitation were obtained from a weather station located onsite.

2.2. Experimental design and agronomic management

Treatments consisted of a factorial combination of two irrigation methods (drip and flood) and four fertilizer and manure treatments including (1) an unfertilized control, and application of 240 kg of available N ha^{-1} in the form of (2) granular urea (Urea), (3) animal manure (Manure), and (4) 50% Urea with 50% Manure (U + M). For drip irrigation, 20% of the urea was band-applied at planting and the remaining 80% through six fertigation events, applied 9, 11, 14, 15, 16, and 17 weeks after planting. For flood irrigation, 30% of urea was band-applied at planting and the remaining 70% applied during irrigation at 9, 11, 14, and 17 weeks after planting where fertilizers were broadcast before irrigation. For both irrigation methods, manure was broadcast evenly onto the soil surface and immediately incorporated into the soil with a rota-cultivator before sowing. The animal manure was a mixture of composted cattle and sheep manure with a C/N ratio of 18 and concentrations of total Kjeldahl N at 15.6 ± 0.6 g N kg^{-1}, total P at 2.0 ± 0.1 g P kg^{-1}, and total K at 16.8 ± 0.3 g K kg^{-1}. Based on the C/N ratio, application rates of manure were determined by assuming that 20% of the total N in the manure would become available by mineralization (Gale et al., 2006). Thus, the Manure and U + M treatments received manure applications at 77.0 and 38.5 Mg ha^{-1}, respectively. For all plots, 120 kg P_2O_5 ha^{-1} as calcium phosphate and 60 kg K_2O ha^{-1} as K_2SO_4 were broadcast onto the soil surface by hand and incorporated into soils before planting. Treatments were laid out in a randomized complete block design with four replicates of each treatment. The size of each plot was 10 m × 6.4 m.

In both years, planting of cotton (c.v. Xinluzao 48) occurred during the 2nd week of April under a plastic-mulch production system (Fig. 1). A flood irrigation was conducted on all plots one day before seeding. A high-density and airtight transparent polythene film was placed to cover 4 rows of cotton with row spacing of 30–50 – 30 cm and a flat soil surface. The space between plants within each row was 10 cm. Each plot had four sheets of plastic film mulch, separated by a 50-cm strip of