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Urea fertigation sources affect nitrous oxide emission from a drip-fertigated cotton field in northwestern China

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ABSTRACT

Drip-fertigated systems are widely used for crop production in arid regions to improve water and nutrient use efficiency. However, the effect of fertilizer nitrogen (N) sources on nitrous oxide (N_2O) emissions from such systems is not well understood. A field experiment was conducted in 2015 and 2016 on a sandy loam soil in Xinjiang, China with plastic-mulch, drip-fertigated cotton (*Gossypium hirsutum* L.) to determine N_2O emissions from different fertilizer N sources. Treatments were established in a factorial design consisting of a 0 N control and three treatments receiving 240 kg N ha^{-1} as (1) polymer-coated urea (ESN), (2) urea alone, or (3) urea with both urease (NBPT) and nitrification (DCD) inhibitors. ESN was banded in the row at planting, whereas the two urea treatments were applied through banding and fertigation. In these treatments, 20% of the urea was banded in the row at planting and the remaining 80% was applied with six fertigation events over the growing season. Seasonal cumulative N_2O emissions (ΣN_2O) for urea alone were 330 g N ha^{-1} and were 27% greater than the control. Compared to urea alone, the ESN treatment increased ΣN_2O by 43% due to the one-time application at planting that resulted in high soil N availability and high N_2O emissions shortly after planting. Compared to urea alone, urea plus the two inhibitors decreased ΣN_2O by 21%. Cotton seed yield and total N uptake was not affected by N sources, while ESN had significantly higher yield-based emission intensity compared to the other N treatments. In general, the seasonal N_2O emissions and N-applied emission factors under the drip-fertigated system were lower than those reported for other agricultural systems. This was likely because of low soil moisture preventing appreciable N_2O emissions. These results demonstrated that addition of urease and nitrification inhibitors could further reduce already low N_2O emissions with soluble urea with drip-fertigation and under plastic mulch condition.

1. Introduction

Nitrous oxide (N_2O) is one of the most important greenhouse gases (GHGs) in the atmosphere, contributing to both global warming and the destruction of stratospheric ozone (Ravishankara et al., 2009). It has a long lifetime of approximately 120 years and a warming potential 265 times greater than that of carbon dioxide (IPCC, 2014). The atmospheric concentration of N_2O has increased considerably from 270 ppbv from the pre-industrial era to near presently 324 ppbv, largely as a consequence of human activities (IPCC, 2013). Emissions from agricultural soils are the major cause of increasing concentrations of N_2O in the atmosphere, primarily because of nitrogen (N) addition (Davidson and Kanter, 2014). Effective fertilizer N management practices are needed to mitigate N_2O emissions from agricultural soils.

Soil N_2O emissions are mainly a result of the microbial processes of nitrification under aerobic conditions and denitrification under anaerobic conditions. Thus N_2O emissions often increase following application of inorganic N fertilizers to soil (Pathak, 1999). Urea (46-0-0) is the most commonly used N fertilizer worldwide due to its high N content, low cost, and ease of transport, storage and application (IFA, 2017). However, urea can be a less effective source of fertilizer N for crops because of loss by ammonia (NH_3) volatilization, nitrate (NO_3^-)

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leaching, N_2O emission, and denitrification to N_2 gas (Zaman and Blennerhassett, 2010). Increasing demand for food as a result of global population growth is expected to be met by greater use of fertilizer N products (Bouwman et al., 2013). It is thus extremely important to develop fertilizer management strategies to increase the use efficiency of crops while reducing N losses to the environment.

The "4R" Nutrient Stewardship framework of using the right source, rate, timing and placement of N fertilizer is widely being explored to increase crop N use efficiency and mitigate N_2O emissions (Snyder et al., 2009). The source of N fertilizer has particularly implications to choice of rate, timing and placement practices to farmers using the "4R" Nutrient Stewardship framework.

Enhanced efficiency N fertilizers (EENF) are formulated with aim to better match crop N demand while reducing N losses to the environment (Akiyama et al., 2010; Halvorson et al., 2014). Two typical EENF products are polymer-coated urea and stabilized urea containing a urease and/or a nitrification inhibitor. Environmentally Smart N (ESN) is a polymer-coated urea product (44-0-0) from which the release of N through the coating is controlled by soil temperature and moisture. Halvorson et al. (2014) summarized studies in Colorado and found ESN reduced N_2O emissions by 42% compared to urea. In contrast, in a field study over multiple site-years, Gao et al. (2015) reported ESN reduced N_2O emissions compared to conventional urea only for warm and wet early growing season conditions of spring wheat. Meta-analysis of N_2O emissions studies by Akiyama et al. (2010) reported that nitrification inhibitors with urea reduced N_2O emissions by 38% compared to urea alone whereas urease inhibitors did not. The more recent meta-analysis by Yang et al. (2016) also concluded the nitrification inhibitors, dicyandiamide (DCD), or 3,4-dimethylpyrazole phosphate (DMPP), decreased N_2O emissions nearly by half regardless of cropping system.

Urease and nitrification inhibitors together with urea is reported to reduce N_2O emissions and increase crop yields more effectively generally in alkaline than acidic soil (Feng et al., 2016; Thapa et al., 2016). However, the inhibitors are not always effective to reduce N_2O emissions from soil amended with urea. For example, a double-inhibitor granular urea product, SuperU, was not effective in reducing N_2O emissions compared to urea for a soil with a high organic carbon and clay content (Asgedom et al., 2014).

Xinjiang autonomous province, located in northwestern China, is an arid region where cotton (*Gossypium hirsutum* L.) is the main cash crop. The planting area of cotton in Xinjiang has increased from 2.0×10^5 ha in 1980 to over 1.8×10^6 ha by 2016, accounting for 54% of total area planted to cotton in China (NBSC, 2016). Almost all cotton production in Xinjiang is using plastic-mulch and drip-fertigation. Plastic-mulch use increases soil temperature, reduces evaporation, and inhibits weeds, resulting in increased yield of cotton fibre and seed (Hou et al., 2010; Li et al., 2014; Günther et al., 2017). The adaptability and profitability of growing cotton with plastic-mulch and drip-fertigation in China have been thoroughly reviewed by Dai and Dong (2014). However, it is unknown if N_2O emissions from soil are affected by use of plastic-mulch and drip-fertigation of cotton. Benefits of higher soil moisture and temperature with plastic-mulch may enhance microbial activity, mineralization of soil C and N, and thus N_2O emissions (Ussiri and Lal, 2013; Hallin et al., 2018). Or perhaps, drip-fertigation may reduce N_2O emissions by better coordination of N application, crop demand, and delivery to roots. Drip-fertigation of N reduced N_2O emissions by 70% compared to furrow-irrigation with split N addition while having increased yield of processing tomato in California (Kennedy et al., 2013). Guardia et al. (2017) reported drip-fertigation greatly reduced soil N_2O emissions because NO_3^- accumulated in dry areas with water-filled pore space (WFPS) below that for nitrification emission losses and NH_4^+ accumulated in wet areas with WFPS suitable for the reduction of N_2O to N_2.

A few studies have evaluated the effect of urease and nitrification inhibitors on N_2O emissions from soil under plastic-mulch and drip-fertigation. Liu et al. (2017) recently reported that the nitrification inhibitor (nitrapyrin) with urea reduced total N_2O emissions and N-applied emission factor (EF) of cotton under plastic-mulch and drip-fertigation compared to urea alone. Tian et al. (2017) reported drip-fertigation of urea with addition of DCD or nitrapyrin reduced N_2O emissions by 66% for an annual double crop system of winter wheat/summer corn in the North Plain of China. It is uncertain if there's benefit to inclusion of the urease inhibitor, NBPT, with DCD and urea with drip-fertigation in lowering N_2O emissions. It's also unknown if polymer-coated urea added at planting as the sole N fertilizer addition reduces soil N_2O emissions for cotton under plastic-mulch and drip-irrigation.

The objective of this study was to determine the efficacy of a polymer-coated urea source, ESN, and soluble urea with urease and nitrification inhibitors for cotton production to reduce soil N_2O emissions under plastic-mulch and drip-fertigation/irrigation in Xinjiang. Area-, fertilizer- and yield-scaled N_2O emissions were determined over two consecutive growing seasons. We hypothesized that use of the double inhibitors and ESN will reduce soil N_2O emissions without reducing cotton yields.

2. Materials and methods

2.1. Site description and soil properties

A field trial was conducted in each of the 2015 and 2016 growing seasons in different fields at the National Grey Desert Soil Station (43°56′ N, 87°28′ E) of the Xinjiang Academy of Agricultural Sciences near Urumqi, Xinjiang, China. The area has a continental arid climate with annual precipitation of 230 mm and evaporation of 1800 mm. Mean annual air temperature is 6.5 °C and the lowest and highest mean monthly air temperatures are −15.0 °C in January and 27.2 °C in July, respectively. The air temperature difference between day and night is usually greater than 15 °C. Mean annual sunshine and the frost-free period are 2594 h and 156 d, respectively. The soil at the field is classified as a grey desert soil in the Chinese soil classification and a Typic Argigypsids in the USDA-NRCS system.

Surface soil (0–20 cm) of the field is a sandy loam (clay 27, silt 343 and sand 630 g kg^{-1}) with bulk density of 1.3 Mg m^{-3}. The trial site in 2015 has surface soil of pH 8.0, electrical conductivity (EC) 229 μS cm^{-1}, organic matter 17.9 g kg^{-1} by wet oxidation, total Kjeldahl N 0.9 g kg^{-1}, 0.5 M $NaHCO_3$ extractable phosphorus (P) 3.4 mg kg^{-1}, 1.0 M ammonium acetate extractable potassium (K) 228 mg kg^{-1}, and NO_3-N 19.0 mg kg^{-1}. The trial in 2016 has soil of pH 8.3, EC 120 μS cm^{-1}, organic matter 13.7 g kg^{-1}, total Kjeldahl N 0.8 g kg^{-1}, extractable P 13.0 mg kg^{-1}, extractable K 197 mg kg^{-1}, and NO_3-N 8.4 mg kg^{-1}. Daily mean air temperature and total daily precipitation were obtained from a weather station onsite.

2.2. Experimental design and agronomic management

For each trial, treatments were established in a factorial design consisting of a 0 N control (Control) and three treatments receiving 240 kg N ha^{-1} as (1) polymer-coated urea (ESN), (2) urea alone (Urea), or (3) urea with both urease (NBPT) and nitrification (DCD) inhibitors (U + DI). All plots received 120 kg P_2O_5 ha^{-1} as calcium phosphate and 60 kg K_2O ha^{-1} as K_2SO_4 by hand spread and incorporated by a rotcultivar before planting. Granular urea was applied with 20% of total applied N as a band to each intended plant row before seeding, and the remaining 80% N solubilized and applied over six fertigation events applied 9, 11, 14, 15, 16, and 17 weeks after planting. ESN was banded to each intended plant row before seeding. For treatment U + DI, NBPT was applied using the same schedule as urea and DCD was all banded in the plant row before seeding. Both NBPT and DCD were applied at a rate of 1% urea N. Treatments were laid out in a randomized complete block design with four replicate plots. The size of each plot was 10 m × 6.4 m.