Application effects of coated urea and urease and nitrification inhibitors on ammonia and greenhouse gas emissions from a subtropical cotton field of the Mississippi delta region

Zhou Tian [a,b], Jim J. Wang [b,*], Shuai Liu [a,b], Zengqiang Zhang [a,*], Syam K. Dodla [b], Gerald Myers [b]
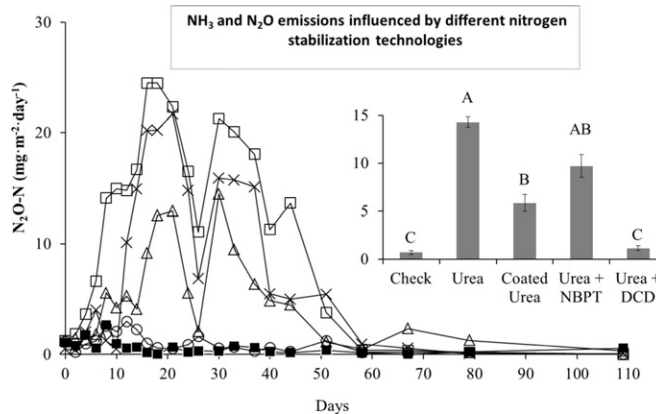
[a] College of Resources and Environment, Northwest A&F University, Yangling, Shaanxi, China
[b] School of Plant, Environment & Soil Sciences, Louisiana State University Agricultural Center, Baton Rouge, LA 70803, USA

HIGHLIGHTS

- Nitrogen loss to the atmosphere dominated by higher emission of N_2O-N over NH_3-N
- Urease inhibitor NBPT minimizes NH_3 emission in subtropical cotton production
- Inhibitors/polymer-coated urea effective as mitigation strategies for N_2O emission
- Nitrogen stabilization had little consistent effect on CO_2 and CH_4 fluxes

GRAPHICAL ABSTRACT

ABSTRACT

Nitrogen (N) fertilization affects both ammonia (NH_3) and greenhouse gas (GHG) emissions that have implications in air quality and global warming potential. Different cropping systems practice varying N fertilizations. The aim of this study was to investigate the effects of applications of polymer-coated urea and urea treated with N process inhibitors: NBPT [N-(n-butyl)thiophosphoric triamide], urease inhibitor, and DCD [Dicyandiamide], nitrification inhibitor, on NH_3 and GHG emissions from a cotton production system in the Mississippi delta region. A two-year field experiment consisting of five treatments including the Check (unfertilized), urea, polymer-coated urea (ESN), urea + NBPT, and urea + DCD was conducted over 2013 and 2014 in a Cancienne loam (Fine-silty, mixed, superactive, nonacid, hyperthermic Fluvaquentic Epiaquepts). Ammonia and GHG samples were collected using active and passive chamber methods, respectively, and characterized. The results showed that the N loss to the atmosphere following urea-N application was dominated by a significantly higher emission of N_2O-N than NH_3-N and the most N_2O-N and NH_3-N emissions were during the first 30–50 days. Among different N treatments compared to regular urea, NBPT was the most effective in reducing NH_3-N volatilization (by 58–63%), whereas DCD the most significant in mitigating N_2O-N emissions (by 75%). Polymer-coated urea (ESN) and NBPT also significantly reduced N_2O-N losses (both by 52%) over urea. The emission factors (EFs) for urea, ESN, urea-NBPT, urea + DCD were 1.9%, 1.0%, 0.2%, 0.8% for NH_3-N, and 8.3%, 3.4%, 3.9%, 1.0% for N_2O-N, respectively. There were

* Corresponding authors.
  E-mail addresses: jjwang@agcenter.lsu.edu (J.J. Wang), zqzhang@nwsuaf.edu.cn (Z. Zhang).

no significant effects of different N treatments on CO_2-C and CH_4-C fluxes. Overall both of these N stabilizers and polymer-coated urea could be used as a mitigation strategy for reducing N_2O emission while urease inhibitor NBPT for reducing NH_3 emission in the subtropical cotton production system of the Mississippi delta region.

1. Introduction

Nitrous oxide (N_2O) and methane (CH_4) are important greenhouse gases due to their greater global warming potential as compared to carbon oxide. Agriculture accounts for 80% and 50% of the total emissions of N_2O and CH_4, respectively (IPCC, 2007). Ammonia (NH_3), while not a direct greenhouse gas (GHG), its emission into the atmosphere affects air quality besides nutrient loss due to the fact it is a precursor of $PM_{2.5}$. Soil emission of (GHG) and NH_3 is influenced by various factors including crops type, soil properties, field management, weather condition, fertilizer, etc. (Bremner, 1997; Bouwman et al., 2002; Sutton et al., 2008). Among these, nitrogen (N) fertilization practice is one of the most important factors (Snyder et al., 2009).

Nitrogen, a major essential element for plant growth, is limited in agricultural soils (Kawakami et al., 2013). For its high N content ($460 \text{ g N} \cdot \text{kg}^{-1}$), urea has been used as the primary solid N fertilizer in agricultural crop production (Heffer and Prud'homme, 2011; Soares et al., 2012). After soil application, granule urea is hydrolyzed into NH_4^+, Hydroxyl (OH^-), and carbonate (CO_3^{2-}) ions within 1 to 2 days, which leads to a sharp pH rise in surrounding area and subsequent NH_3 losses to the atmosphere (Wang et al., 1991). The magnitude of NH_3 volatilization is influenced by soil pH, texture, buffering capacity, temperature, and moisture, and it is generally greater under warm climates (Bouwman et al., 2002). In the past, soil NH_3 emission was primarily studied as one of N nutrient loss pathway, and only recently has it begun to draw much attention for its effect on atmospheric quality as the precursor of $PM_{2.5}$ (Zaman et al., 2008, 2009a,b; Zaman and Blennerhassett, 2010; USEPA, 2011). On the other hand, NH_3 can act as a secondary source of N_2O production. Various studies have shown that application of urea increases the soil release of N_2O to the atmosphere (Bremner, 1997; Jantalia et al., 2012; Fernández et al., 2015).

Nitrous oxide is generated primarily through microbial nitrification and denitrification although abiotic processes also contribute to N_2O production (Butterbach-Bahl et al., 2013). While nitrification is strictly aerobic, denitrification is generally anaerobic process (Khalil et al., 2004). Beside pH, organic matter, and C/N ratio, N_2O emission from nitrification is primarily affected by temperature and soil density whereas its release from denitrification is influenced by soil water content or amount of water filled pore spaces (Davidson and Swank, 1986; Bremner, 1997). Climate conditions and regional differences are likely to play a significant role in controlling overall N_2O emissions. For instance, N_2O emission factor from cotton fields in Australia was found to range from 0.4% to 0.53% (Scheer et al., 2012) while it was reported to be 0.95% in northern China (Liu et al., 2010).

To reduce N losses as NH_3 and N_2O emissions and enhance N fertilizer use efficiency, various attempts of N stabilization have been developed. These include physical polymer coating and urea treated with urease inhibitors and nitrification inhibitors (Turner et al., 2010; Sanz-Cobena et al., 2012; Halvorson et al., 2014). Urease inhibitor abates NH_3 emissions by slowing the hydrolysis of urea, which limits the pool of NH_4^+ for potential volatilization loss (Turner et al., 2010). Among the urease inhibitors, N-(n-butyl) thiophosphoric triamide (NBPT) has been used widely and found under highly effective at mitigating NH_3 emissions at relatively low concentration field conditions (Sanz-Cobena et al., 2008). However, there have been very few studies showing the effect of urease inhibitors on the release of other N forms (i.e. NO, N_2O and NO_3^-) from urea-based fertilizers (Sanz-Cobena et al., 2012). Nitrification inhibitors such as dicyandiamide (DCD), nitropyrin, and 3,4 dimethyl pyrazole phosphate have been used for reducing the N losses

through slowing the genus of nitrifying bacteria and nitrosomonas responsible for the oxidation of NH_4^+ to NO_2^-, therefore reduce NO_3^- leaching and N_2O emissions (Cameron et al., 2005; Trenkel, 2010). Among these, DCD has been widely used in agriculture for its low cost, less volatility and good solubility in water. On the other hand, due to the previous focus mostly on agronomic improvement of N nutrient use efficiency, there has been very few systematic evaluations of the fertilizers with N stabilizers as a mitigation strategy for minimizing the emissions of NH_3 and GHGs especially N_2O even though conservation and environmental agencies have recommended the use (Halvorson et al., 2014). Limited available literature has showed varying effects of controlled-release and stabilized N fertilizers on N_2O emissions (Menéndez et al., 2009; Akiyama et al., 2010; Sistani et al., 2011; Li et al., 2012; Asgedom et al., 2014; Fernández et al., 2015). Compounded factors of cropping systems with different tillage, irrigation, and fertilization practices as well as regional climate conditions likely contributed to the differences among the reported results (Zebarth et al., 2012; Asgedom et al., 2014; Halvorson et al., 2014; Fernández et al., 2015).

Cotton (*Gossypium hirsutum* L.) production in United States ranks the third behind China and India. These three countries account for two-thirds of the world's cotton production (USDA, 2013). There were only few available studies on GHG emissions from cotton production systems but none has evaluated the effects of controlled release and stabilized N fertilizers. In the U.S.A., cotton production is primarily concentrated in south central, southeast, and western states (Alabama, Louisiana, Mississippi, Georgia, Texas and California). The subtropical cotton production in the Mississippi delta region is subjected to hot and humic climate influence, which could leads to significant gas emissions. Therefore the objective of this study was to assess the efficacy of controlled-release and stabilized N fertilizer as a mitigation technology to reduce NH_3 and GHG emissions from the cotton production systems in the Mississippi delta region. To our knowledge, this is the first study to report an evaluation of the polymer-coated (slow-release) urea and N stabilizers-treated urea for both NH_3 and GHG emissions from a cotton field.

2. Materials and methods

2.1. Site and experimental description

Cotton field experiment with reduced tillage, which is common in the region, was established at the Central Research Station, Louisiana State University Agriculture Center, Baton Rouge, LA, USA (30°21′N, 91°10′W). The soil at the site was a Cancienne loam (fine-silty, mixed, superactive, nonacid, hyperthermic Fluvaquentic Epiaquepts). The soil contains 20.5% clay, 44.8% silt and 34.7% sand. It has a pH of 6.2, total N of 0.59%, and total C of 6.62%.

Cotton cultivar PHY499WRF was planted on June 7th, 2013 for the first year and June 6th, 2014 for the second year. Field experiment was carried out with a randomized complete block design and included five fertilization treatments: check (unfertilized), urea, polymer-coated urea (environmentally smart nitrogen [ESN] with methylene di-urea as conditioner, 44% N, Agrium Advanced Technologies), urea plus NBPT (AGROTAIN, Koch Fertilizer, LLC), and urea plus DCD (Sigma-Aldrich Co. LLC). Each treatment was replicated four times. Each plot contains four 15.24-meter long rows with an overall plot width of 0.96 m. Treatment fertilizers were side-dressed on the 20 days after planting at a rate $112 \text{ kg} \cdot \text{N} \cdot \text{ha}^{-1}$. The inhibitors, NBPT and DCD, were mixed with urea at