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Ammonia and greenhouse gas emissions from a subtropical wheat field under different nitrogen fertilization strategies

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ABSTRACT

Minimizing soil ammonia (NH₃) and nitrous oxide (N₂O) emission factors (EFs) has significant implications in regional air quality and greenhouse gas (GHG) emissions besides nitrogen (N) nutrient loss. The aim of this study was to investigate the impacts of different N fertilizer treatments of conventional urea, polymer-coated urea, ammonia sulfate, urease inhibitor (NBPT, N-(n-butyl) thiophosphoric triamide)-treated urea, and nitrification inhibitor (DCD, dicyandiamide)-treated urea on emissions of NH₃ and GHGs from subtropical wheat cultivation. A field study was established in a Cancienne silt loam soil. During growth season, NH₃ emission following N fertilization was characterized using active chamber method whereas GHG emissions of N₂O, carbon dioxide (CO₂), and methane (CH₄) were by passive chamber method. The results showed that coated urea exhibited the largest reduction (49%) in the EF of NH₃-N followed by NBPT-treated urea (39%) and DCD-treated urea (24%) over conventional urea, whereas DCD-treated urea had the greatest suppression on N₂O-N (87%) followed by coated urea (76%) and NBPT-treated urea (69%). Split fertilization of ammonium sulfate-urea significantly lowered both NH₃-N and N₂O-N EF values but split urea treatment had no impact over one-time application of urea. Both NBPT and DCD-treated urea treatments lowered CO₂-C flux but had no effect on CH₄-C flux. Overall, application of coated urea or urea with NPBT or DCD could be used as a mitigation strategy for reducing NH₃ and N₂O emissions in subtropical wheat production in Southern USA.

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Introduction

Application of nitrogen (N) fertilizer is an important practice for increasing crop output in agricultural production due to its limited availability in soils. Time, type and amount of N fertilizer application can, however, have significant implications for air quality and emissions of greenhouse gases (GHGs). The loss of gaseous N as ammonia (NH₃) following N fertilization poses a threat to the environment besides its

impact to lower N nutrient use efficiency by plants and to affect soil process such as acidification due to ammonia oxidation. Ammonia is also a precursor of fine particle matter (PM_{2.5}), which has significant effect on regional air quality (Wang et al., 2005; Behera et al., 2013). Agriculture accounts for about 50% of all NH₃ emissions worldwide (Sommer et al., 2004). Potential risk of NH₃ volatilization from urea fertilizer varies significantly with the N fertilizer applied, depending on soil and climatic conditions (Watson, 1990; Bishop and

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Manning, 2010; Tian et al., 2015). In addition, NH_3 emissions and the subsequent deposition onto land and water also represent an indirect emission source of N_2O , an important GHG (Haynes and Sherlock, 1986).

The GHGs are those that absorb infrared radiation in the atmosphere, leading to the trapping of heat to warm the surface of the Earth. There are three major GHGs associated with agricultural production— CO_2 , CH_4 , and N_2O . Among the three, CO_2 is cycled in the largest amounts through agricultural cropping systems due to photosynthesis and plant residue decomposition, whereas CH_4 and N_2O have global warming potentials of 25 and 298 times greater than CO_2 (IPCC, 2007). Methane emission is primarily by methanogenesis during anaerobic digestion of organic matter under anoxic environments, whereas N_2O emission results mainly from two microbial processes in soil: nitrification and denitrification (Bange, 2000). Agricultural practices, especially fertilization, play a significant role in production and consumption of GHGs (Rastogi et al., 2002; Smith et al., 2008). While N fertilizer application can increase soil CO_2 flux through enhancing N availability for microbial degradation of crop residue (Sainju et al., 2008; Wilson and Al-Kaisi, 2008), its effect on CH_4 emission is complex and sometimes contradictory (Lindau, 1994). For example, both increased and decreased oxidation capacity of soil for atmospheric CH_4 emission has been observed by enhanced NH_4^+ concentrations through fertilization (Van den Pol-van Dassel et al., 1999; Bodelier and Laanbroek, 2004). On the other hand, many factors likely affect N_2O emissions following N fertilization including field management practices of specific cropping systems and environmental and soil parameters (Hutchinson and Davidson, 1993; Ambus et al., 2006; Cardenas et al., 2010). With current intensive cropping systems, large N fertilizer losses including nitrate (NO_3^-) leaching, NH_3 volatilization and N_2O emissions have caused significant environmental concerns besides the decreased N use efficiency.

To reduce N losses, various N fertilizer stabilization technologies including physical polymer coating and treatment with urease and nitrification inhibitors have been developed to enhance its efficiency (Brown et al., 1988; Turner et al., 2010; Sanz-Cobena et al., 2012). Among the urease inhibitors, N-(n-butyl) thiophosphoric triamide (NBPT) has been used widely and found to be highly effective in mitigating NH_3 emissions (Sanz-Cobena et al., 2008). On the other hand, dicyandiamide (DCD), nitropyrin, and 3,4 dimethyl pyrazole phosphate have been used for reducing the N losses of NO_3^- leaching and N_2O emissions through inhibiting the genus of nitrifying bacteria and nitrosomonas responsible for the oxidation of NH_4^+ to NO_2^- (Cameron et al., 2005; Trenkel, 2010). While earlier efforts were primarily aimed at improving agronomic benefits (Brown et al., 1988; Frye et al., 1989), recent focus has been shifted to use these enhanced efficiency N fertilizers (EENFs) as a strategy to curb GHG gas emissions and air quality-sensitive NH_3 volatilization (Halvorson et al., 2014; Ding et al., 2015; Tian et al., 2015). On the other hand, available studies conducted in different regions revealed inconsistent effects or even contradicting results of these EENFs on NH_3 and GHG emissions (Sistani et al., 2011; Parkin and Hatfield, 2013; Asgedom et al., 2014; Fernández et al., 2015). These conflicting results emphasize the need for the evaluation of

these N stabilization technologies as a strategy for mitigation of N_2O and NH_3 emissions for specific regions and cropping systems (Tian et al., 2015).

Wheat (*Triticum aestivum* L.) is the third largest crop in the U.S. and is produced in nearly every state. Wheat production in the south central region is more influenced by weather conditions. Unlike most of the other crops, wheat has distinct varieties that are produced in different regions (Voche and Ali, 2013), which indicates more regional variation in response to field management practices. Across the globe, research on the effectiveness of EENFs on GHG emissions from wheat fields is very limited. Available studies were concentrated in Asia and/or under temperate climate regions (Majumdar et al., 2002; Malla et al., 2005; Ding et al., 2011, 2015). In addition, besides one-time application of major N source such as urea, a split fertilization regime using ammonium sulfate had been commonly practiced to provide sulfur nutrition to wheat in early spring growth. Therefore, the objective of this study was to investigate the effect of different N fertilizers (urea, coated urea, ammonia sulfate), application pattern and inhibitors (NBPT and DCD) on fluxes of NH_3 , N_2O , CO_2 , and CH_4 from a subtropical wheat field in the southern central region of the USA.

1. Materials and methods

1.1. Experimental site and treatments

A wheat field was established in a Cancienne silt loam soil (fine-silty, mixed, superactive, nonacid, hyperthermic Fluvaquentic Epiaquepts) at the Central Research Station, Louisiana State University Agriculture Center, Baton Rouge, LA. The region has a humid subtropical climate, with a typical mean temperature of 19.7°C and rainfall of 1411 mm/year. The field experiment consisted of five N fertilizer treatments in 2013, including the control (CK, no fertilizer applied), two one-time applications of urea (U) and polymer-coated urea (CU) at 112 kg N/ha, and two separate split applications of urea (SU) only and ammonia sulfate-urea combination (SASU) with each split at 56 kg N/ha. During SASU split application, ammonium sulfate was first applied in February and followed by urea application in March. Two additional N fertilizer treatments with urea plus urease inhibitor NBPT (U + N) and urea plus nitrification inhibitor DCD (U + D) at 112 kg N/ha were implemented in 2014. The inhibitors, NBPT and DCD, were mixed with urea at a rate of 10% of the fertilizer (w/w), respectively, one day before fertilization to the soil (Tian et al., 2015). The polymer-coated urea (environmentally smart nitrogen (ESN) with methylene di-urea as conditioner, 44% N) was from Agrium Advanced Technologies, Inc. The NBPT urease inhibitor was AGROTAIN from Koch Fertilizer, LLC and the nitrification inhibitor DCD was from Sigma-Aldrich Co. LLC. The wheat variety planted was AGS 2035. All the fertilizer applications in this experiment were broadcasted before sampling. The field was in a conventionally-tilled winter wheat-soybean-winter wheat rotation for the past 3 years before the initiation of the trial. The field experiment was carried out in a randomized block design with four replications in 6.08 m in length \times 1.52 m in width plots. Selected

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