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Effect of nitrogen fertilization and residue management practices on ammonia emissions from subtropical sugarcane production

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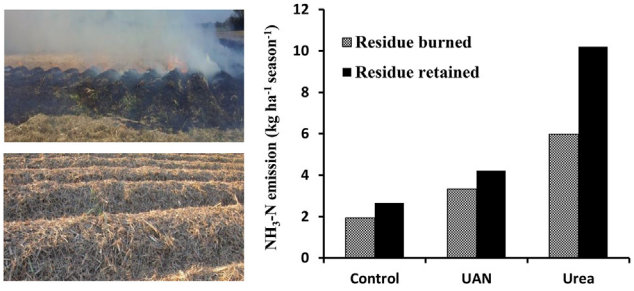
HIGHLIGHTS

- Both N fertilization and residue management scheme significantly affected NH_3 emissions.
- UAN application reduced NH_3 emission factor by 70% as compared to urea in sugarcane production.
- Retention of harvest residue increased NH_3 emission than burning approach regardless of N source.
- Significant NH_3 emission occurred within 4 weeks of fertilization and increased with increasing WFPS.

GRAPHICAL ABSTRACT



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ABSTRACT

Ammonia (NH_3) emission from soil is a loss of nitrogen (N) nutrient for plant production as well as an issue of air quality, due to the fact that it is an active precursor of airborne particulate matters. Ammonia also acts as a secondary source of nitrous oxide (N_2O) emission when present in the soil. In this study, the impacts of different sources of N fertilizers and harvest residue management schemes on NH_3 emissions from sugarcane production were evaluated based on an active chamber method. The field experiment plots consisting of two sources of N fertilizer (urea and urea ammonium nitrate (UAN)) and two common residue management practices, namely residue retained (RR) and residue burned (RB), were established on a Commerce silt loam. The NH_3 volatilized following N fertilizer application was collected in an impinger containing diluted citric acid and was subsequently analyzed using ion chromatography. The NH_3 loss was primarily found within 3–4 weeks after N application. Average seasonal soil NH_3 flux was significantly greater in urea plots with NH_3-N emission factor (EF) twice or more than in UAN plots (2.4–5.6% vs. 1.2–1.7%). The RR residue management scheme had much higher NH_3 volatilization than the RB treatment regardless of N fertilizer sources, corresponding to generally higher soil moisture levels in the former. Ammonia-N emissions in N fertilizer-treated sugarcane fields increased with increasing soil water-filled pore space (WFPS) up to 45–55% observed in the field. Both N fertilizer sources and residue management approaches significantly affected NH_3 emissions.

1. Introduction

Gaseous ammonia (NH_3) emission following N fertilization is one of the major pathways of nitrogen (N) loss from a soil profile which leads to the reduction in N use efficiency by plants. It plays

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an important role in atmospheric chemistry by neutralizing precipitation and aerosol formation (Anderson et al., 2003; Behera et al., 2013a,b). Ammonia itself is not considered a major air pollutant according to the Clean Air Act (CAA), but it acts as an active precursor of $PM_{2.5}$ formation in the air and a secondary source for nitrous oxide (N_2O) emissions when present in the soil. Under typical atmospheric conditions, NH_3 reacts with gaseous sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) to form secondary fine and ultrafine particles like ammonium sulfate [$(NH_4)_2SO_4$] and ammonium nitrate [NH_4NO_3], which are highly responsible for different human health issues, especially respiratory problems (Seinfeld and Pandis, 1998; Anderson et al., 2003). It has been reported that ammonium sulfates contribute more than 40% of the total $PM_{2.5}$ of the southeastern part of the United States (USEPA, 2014). In addition, sulfate and nitrate aerosols can influence global radiation budget by acting as cloud condensation nuclei (CCN) and scattering incoming solar radiation (Bauer et al., 2007; Myhre et al., 2009; Behera et al., 2013a,b).

Major sources of NH_3 emission include livestock production, fertilizer application; human and animal waste, biomass burning, and soil biogenic processes (Bouwman et al., 1997; Wu et al., 2008). Agricultural application of synthetic fertilizers can contribute about 12–16% of the total global atmospheric NH_3 emissions (Pain et al., 1998; Stephen and Aneja, 2008). Although there have been emission factors (EFs) of NH_3 from agricultural uses of N fertilizers in the past, many current available EFs did not consider specific agricultural production systems and contained various inaccuracies (Goebes et al., 2003). The magnitude of NH_3 emissions from N fertilizers is influenced by various factors including type and quantity of fertilizers used, timing and techniques of fertilizer application, soil moisture content as well as other soil & meteorological conditions. The majority of NH_3 emissions from agricultural fields usually occur within a few days of fertilizer application (Ruijter et al., 2010; Turner et al., 2012; Tian et al., 2015). However, the accurate measurement of atmospheric NH_3 concentration is often very difficult due to the fact that NH_3 is a sticky gas and can easily be adsorbed by almost all surfaces (Anderson et al., 2003; Behera et al., 2013a,b). In addition, under particular inorganic aerosol system (such as ammonium-sulfate-nitrate-water), nitrate and sulfate compete for available NH_3. At sulfate concentration of >9 μg m^{-3}, ammonium-nitrate aerosol concentration was found to be near zero (West et al., 1999). Therefore, understanding NH_3 emission from different agricultural production systems is very important for assessing the impact of management practices on potential air quality in that region.

Sugarcane is one of the major row crops grown in many parts of the world. In the mainland U.S., sugarcane production is concentrated in Louisiana, Florida, and Texas. Sugarcane produces large biomass and requires significant amounts of nutrients especially N and K and special land management practices (Fageria et al., 1997; França et al., 2012). Solid urea has traditionally been used for agricultural crop production but application of liquid urea ammonium nitrate (UAN) is increasingly becoming popular especially in southern USA for sugarcane production in recent years. This change in N fertilizer source likely has different effects on NH_3 loss dynamics and subsequently the air quality.

Field management of sugarcane residues also varies widely across the globe. For instance, in Australia, sugarcane harvest residues (trash) are generally kept as such in the field to conserve soil moisture needed for better ratoon production (Wood, 1991; Fageria et al., 1997), whereas, in-situ biomass burning of the sugarcane residues is a common practice in Brazil and major parts of the U.S. (França et al., 2012). Two open-field burnings of sugarcane residues are often carried out in U.S. sugarcane production, before-harvest burning of standing cane and after-harvest ground burning of combine residue. The former is to eliminate leafy trash for easy combining (cutting) and sugar milling processing, whereas the latter is to prevent the yield loss of subsequent ratoon crops if the residue is not removed (Viator et al., 2008, 2009, Viator, 2009; Udeigwe et al., 2010). The latter is especially true in subtropical sugarcane production, such as in Louisiana, due to negative soil water-temperature relations of relatively cold and wet winter, production of allelochemicals, and high populations of overwintering sugarcane borers and sugarcane beetles (Richard, 2001; Kennedy and Arceneaux, 2006; Viator et al., 2008). Although sweeping residue after combine harvesting has recently been suggested as an alternative solution to this issue, the limited harvest time window in a wet winter, especially for the late-harvested plant cane and first stubble cane crops, makes such an option difficult to be realized (Viator, 2009). An approximate 38% of the sugarcane crop area was burned during 2013 in the US (USEPA, 2015). While various studies have investigated impacts of residue retention on runoff water quality (Southwick et al., 2001; Viator et al., 2009; Udeigwe et al., 2010), there has been very little information concerning the effect of these sugarcane residue management practices on ammonia emission from soil, an important factor that has both N efficiency and air quality implications. Few studies have focused on other crops under different climate regions (Hutchings et al., 2001; Hyde et al., 2003; Gong et al., 2013; Yang et al., 2015; Zhang et al., 2011; Bosch-Serra et al., 2014). Therefore, the goal of this study was to evaluate the emission losses of ammoniacal N from sugarcane production as impacted by two common N fertilizer sources (urea and UAN) and two residue management practices (residue retained, RR and residue burn, RB) in the subtropical region of southern U.S.A.

2. Materials and methods

2.1. Site location and characteristics

The field experiments were carried out at the Louisiana State University AgCenter St. Gabriel research station (USA, 30°15′13″N 91°6′5″W) in 2012 and 2013. First year and second year stubble sugarcane (*Saccharum officinarum*) was used as the planting material for 2012 and 2013, respectively. The soil of the experimental site was a commerce silt loam (Fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts). Surface soil samples (15 cm depth) from the site were taken before the field experiment and analyzed for particle size distribution, cation exchange capacity (CEC), pH, electrical conductivity (EC), total N, total C and different nutrients (P, K, Ca, Mg, and S). Physical and chemical characteristics of the background soil of the field experiment are presented in Table 1.

Additional soil samples were also collected throughout the seasons in both 2012 and 2013 to determine water filled pore space (WFPS) during gas sampling for measuring NH_3 fluxes. The WFPS in percentage was calculated using the formula:

$$\Psi = (\Phi v/TP)^{*}100;$$

where Ψ is the WFPS (%), Φv is the volumetric water content (%) and TP is the total porosity (%) of the soil.

2.2. Fertilizer treatments and residue managements

Field experiments consisting of 6 treatments (one control, two N sources, and two residue management approaches; $3 \times 2 = 6$) were established in 2012. For two N fertilizer source treatments, it was applied at the rate of 135 kg N ha^{-1} in the form of granular urea (45.9% N) and liquid urea ammonium nitrate (UAN; 31.9% N). The