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Impacts of urea deep placement on nitrous oxide and nitric oxide emissions from rice fields in Bangladesh

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ABSTRACT

Urea deep placement (UDP) increases nitrogen use efficiency (NUE) in lowland rice fields by reducing ammonia volatilization, surface runoff and increasing nitrogen uptake. However, its effects on N losses as nitrous oxide (N_2O) and nitric oxide (NO) are not yet clear. We conducted field experiments at two locations of Bangladesh — Bangladesh Agricultural University (BAU) and Bangladesh Rice Research Institute (BRRI) — to determine the effects of UDP vs broadcast urea on N_2O and NO emissions from rice fields.

N_2O and NO emissions were measured from three N fertilizer treatments (control [0 kg N/ha], UDP, broadcast urea) using automated gas sampling and analysis system continuously for three rice growing seasons — *Aus* (May–Aug), *Aman* (Aug–Dec) and *Boro* (Jan–May). Urea was applied as 2–3 split application, while for UDP treatment, urea briquettes were deep placed (7–10 cm depth) between 4 hills of rice at alternate rows to meet recommended N rates in a single application. Treatments were arranged in a randomized complete block design with three replications and N_2O and NO measurements were done at every three-hour interval.

N_2O emissions were sporadic and event specific. Peaks in N_2O emissions were observed after broadcast application of urea, during dry period and after re-flooding of the dry soil. For the rest of the time during the rice-growing season, emissions were very low to negligible. However, across the rice-growing seasons, UDP significantly ($P < 0.05$) reduced N_2O emissions compared with broadcast urea. Moreover, N_2O emissions showed significant spatial and seasonal variations. They were higher during *Boro* season compared with *Aus* and *Aman* seasons and at BAU site than that of BRRI. Conversely, emissions between *Aus* and *Aman* seasons and between control and UDP treatments were similar. In contrast to N_2O emissions, NO emissions were negligible and not affected by fertilizer treatment. However, significant spatial and seasonal variations were observed, with higher NO emissions at BRRI site compared with BAU and during *Boro* than that of *Aus* season.

1. Introduction

Nitrogen (N) plays a major role in crop production. Increases in N fertilizer use have boosted crop production to feed a growing world population. However, nitrogen use efficiency (NUE) in lowland rice fields is generally very low. The N loss is higher specifically when prilled urea (PU) is conventionally applied as broadcast where the recoveries of applied N are as low as 30–45% (Savant and Stangel, 1990; Sommer et al., 2004). More than 50% of applied N is not assimilated by plants and is lost through different mechanisms such as ammonia (NH_3) volatilization, surface runoff, leaching and nitrification–denitrification (Dong et al., 2012; Hayashi et al., 2006; Savant and Stangel, 1990; Singh et al., 1995; Watanabe et al., 2009; Zhao et al., 2009). Therefore, N use is associated with several negative environmental consequences, including increased emissions of nitrous oxide (N_2O) and nitric oxide (NO). N_2O, one of the major greenhouse gases responsible for global warming, is produced during nitrification and denitrification (Davidson et al., 2000; Firestone and Davidson, 1989). In addition to being a greenhouse gas, N_2O emission is the single most important ozone-depleting emission and is expected to remain the largest throughout the 21st century (Ravishankara et al., 2009). Moreover, nitrification–denitrification produces nitric oxide (NO), an environment pollutant that participates in photochemical reactions in the troposphere that produce ozone (Davidson et al., 2000).

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Atmospheric increase in N_2O concentration is mainly governed by anthropogenic sources. The agricultural sector is one of the major contributors, emitting about 60% of total anthropogenic N_2O (Smith et al., 2007). Emissions of N_2O and NO are mainly associated with N fertilizer use (or soil N content) and water regime. Generally, emissions increase with increasing N rates, particularly when N is applied in excess, i.e., beyond plant uptake. N_2O direct soil emissions from agriculture are often estimated using the default IPCC emission factor (EF) of 1% of applied N (IPCC, 2006). This EF is based on a large number of measurements (Bouwman et al., 2002; Stehfest and Bouwman, 2006) which lead to a mean value of 0.9%. Similarly, the global mean fertilizer-induced emission for NO is equivalent to 0.7% of applied N (Bouwman et al., 2002). Though IPCC (2006) considers the round value of 1% of applied N, N_2O emissions from agricultural soils show large temporal and spatial variations due to differences in environment, crops, and management (Lesschen et al., 2011). Moreover, the differences in measurement methodology also contribute to the large variations on reported emissions.

Generally, N_2O emissions are event-specific and appear only after irrigation (or rainfall, if upland crop), after N fertilization, and during the drying of flooded soil or during dry fallow periods (Bronson et al., 1997a, 1997b; Sander et al., 2014). The emission peaks appear only for a few hours to days. However, most of the studies measured emissions at weekly or biweekly intervals. The emissions reported from manual measurement might have missed the possible emission peaks if measurement frequency was not increased after fertilization and irrigation (Sander et al., 2014). Thus, extrapolation of the emissions (measured over wide intervals of time) over a season or a year may either over- or underestimate total emissions. On the other hand, automated continuous measurement includes all the temporal variations; it gives a real estimate of GHG fluxes, particularly for N_2O and NO. However, very limited studies (Scheer et al., 2012) measured N_2O emissions using automated continuous measurement systems. In this study, we report N_2O and NO emissions measured from rice fields using an automated continuous measurement system.

Lowland rice, which is cultivated in continuously flooded conditions, emits relatively less N_2O compared with upland crops (Akiyama et al., 2005, 2006). Because of continuous flooding of the soil, N_2O is further reduced to N_2 during denitrification (Davidson et al., 2000). However, due to increased application of N fertilizer and the change of irrigation practice from continuously flooded to water saving irrigation — alternate wetting and drying (AWD) rice cultivation may emit considerable amount of N_2O (Bronson et al., 1997a; Kim et al., 2013b). Despite the negative environmental consequences, N fertilizer is essential to increasing agricultural production to meet the food demands of a growing world population. Therefore, priority should be given to the best management practices, including optimum rate, source, timing and placement that increase crop productivity and NUE while reducing the negative environmental impacts such as water pollution, greenhouse effect, and ozone layer depletion.

N management studies have been conducted for many years, mainly with the aim of reducing N losses and increasing NUE. Improving the NUE and increasing agricultural productivity have been the major focus of research for the last one to two decades. However, the interest to reduce N_2O and NO emissions while increasing NUE is growing. Some of the N management practices are the use of slow- and controlled-release fertilizers, including polymer- and sulfur-coated fertilizers, nitrification inhibitors, urease inhibitors, and improved placement methods, which reduce the emissions of both gases, particularly N_2O from agricultural fields. Urea deep placement (UDP) is a promising technology that can drastically reduce N losses up to 35% and increase rice yield up to 20% (Mohanty et al., 1999; Savant and Stangel, 1990). UDP increases NUE by reducing N losses such as NH_3 volatilization (Rochette et al., 2013) and surface runoff and increasing plant uptake (Kapoor et al., 2008). UDP is gaining popularity for rice cultivation in some Asian countries such as Bangladesh (IFDC, 2012). Still, studies on the effects of UDP on N_2O and NO emissions are very limited. Reported studies have shown conflicting results. Therefore, this study was conducted to compare the N_2O and NO emissions from UDP vs. urea broadcast in intensive rice cropping systems and to assess their seasonal and spatial variations.

2. Materials and methods

2.1. Experimental site and weather conditions

The field experiments were conducted in two locations of Bangladesh: Bangladesh Agricultural University (BAU), Mymensingh (latitude: 24° 42′ 55″, longitude: 90° 25′ 47″) and Bangladesh Rice Research Institute (BRRI), Gazipur (latitude: 23° 59′ 25″, longitude: 90° 24′ 33″) during *Aus*–*Aman* 2013 and *Boro* 2014. The *Aus* (May–August) and *Aman* (August–November) seasons are considered as wet seasons (rainfed rice), where monsoon rain is typically sufficient for rice production. On the other hand, rice cultivation during the *Boro* (dry season, January–April) season is completely dependent on irrigation supply. The climate is humid sub-tropical monsoon. Average annual rainfall is ca. 1500 mm and primarily received from June to October. Daily rainfall and air temperature for the two locations during the three rice-growing seasons are shown in Fig. 1. The soil of BAU has relatively high organic C and low phosphorus content compared with BRRI soil. The physicochemical properties of the two soils before start of the experiments are shown in Table 1.

2.2. Experimental design and treatments

The three N fertilizer treatments were arranged in a randomized complete block design with three replications in each location. The randomization performed for the first season was the same for the two other seasons in both locations. Experimental plots were 5.6 m × 3.6 m at BAU and 4.3 m × 3.2 at BRRI. The N fertilizer treatments were as follows:

- Control: 0 kg N ha^{-1}
- Urea briquettes: deep placement of urea briquette at 52 kg N ha^{-1} during the *Aus* and *Aman* seasons and 78 kg N ha^{-1} during the *Boro* season.
- Prilled urea (PU): broadcast application at 78 kg N ha^{-1} during the *Aus* and *Aman* seasons or 104 kg N ha^{-1} in the *Boro* season.

Urea briquette (commonly called UDP) of 1.8 g (*Aus* and *Aman* seasons) and 2.7 g (*Boro* season) were deep placed (7– 10 cm depth) at 40 cm × 40 cm spacing (62, 500 placement sites per ha) between four hills of rice at every alternate row. It has been experimentally proven that UDP saves 30–35% urea compared with surface broadcast and produces yield increases of 20% or higher. Therefore, in this study, N rate for UDP is 30% less compared with broadcast PU (recommended dose) (FRG, 2012; Gregory et al., 2010; Kapoor et al., 2008; Savant and Stangel, 1990). Urea briquettes were deep placed as a single application during the first topdressing (7–17 days after transplanting, DAT) of PU. PU was applied as broadcast in two splits during the *Aus* and *Aman* seasons and three equal splits during the *Boro* season. The second and third topdressing of PU were done during maximum tillering (30–35 DAT) and panicle initiation (60–65 DAT) stages, respectively.

2.3. Crop management

Phosphorus (P) (triple superphosphate) and potassium (K) (muriate of potash) fertilizers were applied basally in all the plots during final land preparation at 16 and 42 kg ha^{-1} of P and K, respectively, in the *Aus*–*Aman* seasons. The same two nutrients were applied at 25 and 85 kg ha^{-1}, respectively, during the *Boro* season. In addition, sulfur