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Short communication

Ability of split urea applications to reduce nitrous oxide emissions: A laboratory incubation experiment

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ABSTRACT

Although split fertilizer applications have been suggested as a logical strategy to reduce nitrous oxide (N_2O) emissions by decreasing soil nitrate concentrations, their efficacy remains unclear. A laboratory incubation experiment was performed to determine the effect of split fertilization vs. single fertilization on N_2O emissions. The split urea application reduced the peak N_2O emissions during the incubation period, and the cumulative N_2O emissions were significantly reduced by 28% compared with the single fertilization, although these emissions were influenced by the N fertilizer rate and soil moisture. A higher percentage reduction in cumulative N_2O emissions under the split fertilization occurred at the low (45%) compared with the high fertilizer rate (15%). At the low fertilizer rate (200 N), the split fertilization resulted in a significantly greater reduction in N_2O emissions under the dry soil moisture regime (53%) compared with the wet soil moisture condition (37%). In addition, the split fertilization reduced the cumulative CO_2 emissions by 9% compared with the single fertilization. Therefore, our laboratory results suggest that the split fertilization strategy appears to be a useful method to reduce greenhouse gas emissions in an irrigated agriculture ecosystem.

1. Introduction

Nitrous oxide (N_2O) is an important greenhouse gas (GHG) that contributes to global warming, with a warming potential 298 times higher than that of carbon dioxide (CO_2) when calculated over a 100-year period (IPCC, 2013). Approximately 47% of anthropogenic N_2O emissions are released from agricultural soils through nitrification and denitrification (IPCC, 2013), which are mainly affected by management practices, such as irrigation and fertilization (Burton et al., 2008). In fertilized soils, increasing rates of fertilizer application are the primary cause of enhanced N_2O emissions because nitrate is used as an alternate terminal electron acceptor under aeration conditions to produce N_2O (Burton et al., 2008; Venterea et al., 2012). The soil water content is a major determining factor because of its ability to displace the air-filled pore space (Burton et al., 2008), and the water-filled pore space (WFPS) is well correlated with aerobic and anaerobic microbial activity that subsequently affects nitrification and denitrification (Burton et al., 2008; Ruser et al., 2006).

A logical strategy for reducing N_2O emissions is split fertilization, which would lessen fertilizer-induced pulses by decreasing nitrate concentrations (Aita et al., 2015; Venterea et al., 2012). However, the ability of split fertilization to reduce N_2O emissions is difficult to determine (Burton et al., 2008). Recent publications have reported that cumulative N_2O emissions from split N fertilizer applications were found to be greater than (Venterea and Coulter, 2015), less than (Aita et al., 2015; Burton et al., 2008) or equal to (Weier, 1999; Zebarth et al., 2012) the emissions from single applications. The difference in soil moisture between the single and split fertilizer applications under rain-fed agricultural conditions appeared to be the key factor for these disparate results. Indeed, although previous studies found that N_2O emissions were initially reduced by split fertilization compared with a single application, this benefit was offset by variations in soil moisture conditions following the subsequent split fertilizer application (Weier, 1999). Therefore, we speculate that split applications can reduce N_2O emissions provided soil moisture is not a major factor. In addition, the fertilizer rate will likely affect the ability of split fertilization to reduce N_2O emissions because of the exponential response of N_2O emissions to N rate following split fertilization, in contrast to a linear relationship for single fertilization (Venterea and Coulter, 2015).

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N_2O emissions are difficult to measure because they are highly variable over time, and significant amounts of N_2O emissions are produced hours or even days after fertilizer is applied in the field (Scheer et al., 2014), whereas gas sampling using chamber methods is conducted one to three times per week (Venterea et al., 2012). Therefore, it is difficult to determine the effect of split fertilization on N_2O emissions in field experiments. In this study, a laboratory experiment was conducted to evaluate the ability of split fertilization to reduce N_2O emissions. In addition, CO_2 emissions were also measured to determine the effect of split fertilization on total GHG emissions. We hypothesized that (1) a split application of urea will decrease cumulative N_2O emissions by decreasing the peak N_2O emission, provided soil moisture is thoroughly controlled; and (2) the ability of split fertilization to reduce N_2O emission is affected by soil moisture and the fertilizer rate.

2. Materials and methods

2.1. Site description and soil collection

In October 2013, surface soil samples (0–20 cm) were collected after harvesting an oasis cotton field at the Aksu National Experimental Station (northwestern China; 40°37′N, 80°45′E; 1028 m altitude). The soil was passed through a 2 mm sieve to remove any residue, air dried and stored at room temperature until the start of the experiment. The soil was composed of silt loam (44% sand, 50% silt and 6% clay) and it had an organic carbon content of 4.6 g C kg^{-1} and a pH (1:5 H_2O) of 7.7.

2.2. Experimental design

There were three replicates per treatment for all experiments, and all of the soil samples were maintained in a controlled-environment incubator at 25 °C, which is equivalent to the approximate mean temperature of the irrigation period in the study region (from June to August). A total of 100 g of air-dried soil was added to a glass mason jar (730 ml). The soil moisture was adjusted to 80% WFPS by carefully spraying 33.3 g of distilled water onto the soil to increase the soil moisture, and the soils were pre-incubated for 8 days to reactivate soil microorganisms (Harrison-Kirk et al., 2013). Next, all of the samples were maintained at or dried to their respective moisture contents under the same drying conditions for 12 days. The bulk density of the packed soil (1.26 g cm^{-3}) and particle density (2.65 g cm^{-3}) were used to calculate the WFPS, as described by Guo et al. (2014).

Three fertilization treatments were used: unfertilized (0 N); 7.4 mg urea-N per 100 g dry soil, which is equivalent to 200 kg N ha^{-1} (200 N); and 14.8 mg urea-N per 100 g dry soil, which is equivalent to 400 kg N ha^{-1} (400 N), this application rate is a typical rate for cotton crop in this area. All of the urea-N fertilizers were dissolved in water. Two fertilization strategies were performed: a single application of urea (SI) at 0 day and a split urea application (SP) at 0, 16, 32 and 48 days (Fig. 1).

Two dry/wet treatments were established to simulate fluctuations in soil moisture: moderately wet to dry (soil moisture ranging from 80% to 60% WFPS, MDW) and normally wet–dry (soil moisture ranging from 80% to 40% WFPS, NDW) (Fig. 1). The ranges of the soil water content (40%–80% WFPS) were based on related studies (Yu and Zhao, 2015), and 60% WFPS appears to be the threshold between water-limited and aeration-limited microbial processes (Menéndez et al., 2012). The result of an initial experiment agreed with this statement; the cumulative N_2O emissions increased by 0.38 mg N kg^{-1} as soil moisture increased from 40% WFPS to 60% WFPS. When the soil moisture content was further increased from 60% WFPS to 80% WFPS, the emissions increased by 2.42 mg N kg^{-1} (Table 1S).

Four dry–wet cycles were implemented during the incubation period (64 days), and each cycle consisted of three periods (Fig. 1). In the first period (wet period), all the soils were adjusted to 80% WFPS by carefully spraying distilled water onto the soil surface and incubating the soils under wet conditions for 4 days. In the second

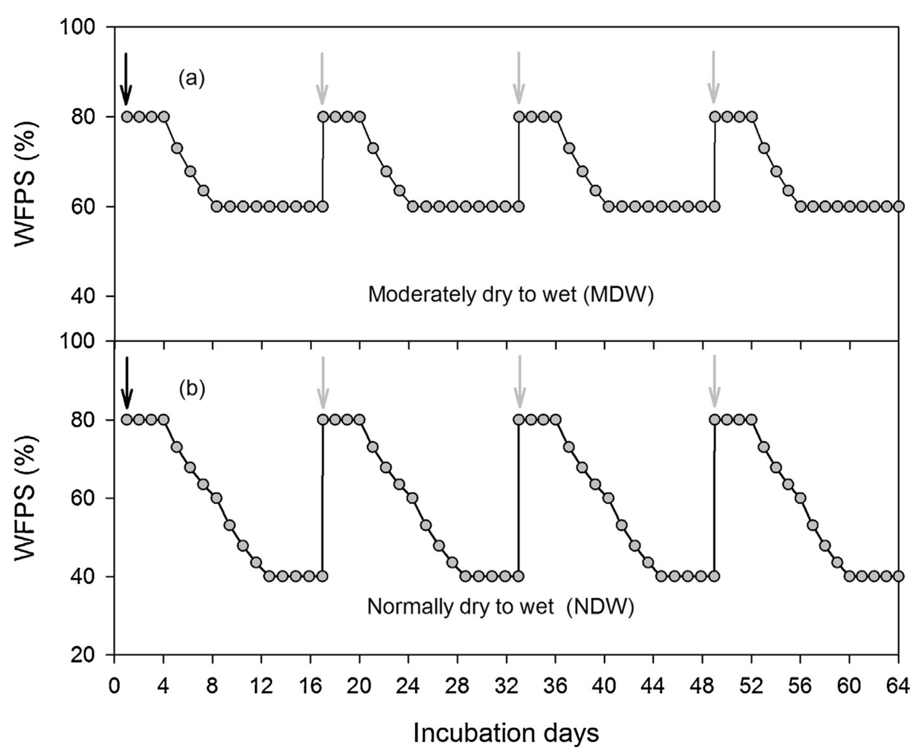

Fig. 1. Variation in soil moisture during the dry/wet cycles. The treatments are moderately wet to dry (MDW) and normally wet to dry (NDW). Black arrows indicate the single and first split urea applications, and gray arrows indicate the second, third and fourth split applications of urea.