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Response of nitrous oxide emission to soil mulching and nitrogen fertilization in semi-arid farmland

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ABSTRACT

Plastic film and gravel mulching have long been used to improve crop production, but few studies have focused on the effects of these mulching practices on nitrous oxide (N_2O) emissions. Understanding the response of N_2O emission to soil surface mulching is beneficial for improving management practices. We performed two field experiments over two years in northwestern China to measure the annual N_2O emissions using the static chamber technique: first, we compared the N_2O emissions from non-mulched (BP), gravel-mulched (GM) and plastic film-mulched (FM) maize (*Zea mays* L.) fields that received an equivalent nitrogen (N) application rate; second, we monitored the N_2O emissions from film-mulched maize fields that received different N application rates [N applied at 0 (N0), 250 (N250) and 380 (N380) kg N ha^{-1}]. Compared to the BP treatment, both the GM and FM treatments markedly improved the soil temperature and moisture, which significantly increased the maize yields and N uptake but did not increase the N_2O emissions, most likely because the decreased soil mineral N content limited the N_2O production. As a result, the yield-scaled N_2O emissions were markedly reduced in the GM and FM treatments, and a greater reduction was observed in the FM treatment due to the higher grain yield. The N_2O emissions persistently increased with an increasing N rate, but the grain yield peaked in the N250 treatment in which the N input was nearly equivalent to the maize N uptake. Consequently, low yield-scaled N_2O emissions were obtained in the N250 treatment (125 and 155 g N_2O–N Mg^{-1} grain in 2011–2012 and 2012–2013, respectively). Thus, we conclude that film mulching combined with an appropriate N input is a preferable management practice to improve the grain yield and to simultaneously minimize the direct N_2O emission intensity in agriculture.

1. Introduction

Mulching soil with natural or artificial materials is a common management practice in worldwide agriculture. As an important traditional technique, gravel has been used as mulch to cultivate crops for many years (Hanks and Woodruff, 1958). Particularly in developing countries, gravel is a preferred material due to its availability and low cost (Yamanaka et al., 2004). In addition, plastic film, an artificial material, has also long been used (Adams, 1967). Numerous studies have reported that these mulching practices can reduce the soil evaporation, increase the soil moisture and temperature (Adams, 1970; Mahrer et al., 1984; Kemper et al., 1994), and improve the soil nutrient availability (Li et al., 2004), thus greatly promoting crop growth and development. Moreover, soil surface mulching can also prevent seed germination or physically suppress the seedling emergence of weeds (Bond and Grundy, 2001) and inhibit soil-borne pathogens (Katan, 2000). Given these positive effects, the application of gravel and plastic film mulching has broadened in recent years (Sharma et al., 2011; Wang et al., 2011; Berger et al., 2013; Gan et al., 2013; Ruidisch et al., 2013). However, few studies have focused on the effects of these mulching practices on the environment, including greenhouse gas emissions.

Nitrous oxide (N_2O) is a potent greenhouse gas (IPCC, 2007) primarily emitted from fertilized farmlands (Smith et al., 2003; Bateman and Baggs, 2005; Montzka et al., 2011). Studies have reported that N_2O emission is driven by the soil temperature and water content (Smith et al., 2003; Snyder et al., 2009). Thus, the N_2O emissions may be increased in gravel- and plastic film-mulched fields because these mulching practices generally improve the soil temperature and moisture. Nevertheless, yield increases resulting

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from mulching drive plant N absorption (Setiyono et al., 2010), resulting in a reduction in the soil mineral N content and most likely limiting the N_2O production (Barton et al., 2008). Few studies have investigated the effects of plastic film mulching on N_2O emission, and some of these studies have reported that N_2O emissions were increased under conditions of mulching (Arriaga et al., 2011; Nishimura et al., 2012), while other studies have reported opposite results (Berger et al., 2013). To improve our knowledge of the soil surface mulching effects on N_2O emissions and to optimize management practices, additional field measurements consisting of different mulching practices are required in various farming systems and areas.

In this study, we performed two field experiments over two years to measure the annual N_2O emissions from maize fields in a region in northwestern China. The first experiment aimed to investigate different mulching practices (gravel and plastic film mulching), and the second experiment aimed to examine the effects of different N application rates under film mulching conditions because this practice is more effective and popular (Gan et al., 2013). The objectives of this study were to (i) assess the effects of soil surface mulching and fertilization on N_2O emissions and (ii) to identify a preferable management practice to simultaneously obtain a high grain yield and low N_2O emission intensity.

2. Materials and methods

2.1. Site description

The field experiments were performed over two years (2011–2012 and 2012–2013) at the Changwu Agricultural and Ecological Experimental Station (35.28°N, 107.88°E, ca. 1200 m above sea level), which is located on the Loess Plateau of northwestern China. The annual mean air temperature is 9.2 °C, and the average annual rainfall is 582 mm, with 73% of the total amount of rain falling during the maize growth season. The main cropping system in this area includes harvesting one crop of maize or wheat per year. According to the Chinese Soil Taxonomy, the soils at this site are Cumuli-Ustic Isohumosols (Gong et al., 2007). The soil properties in the top 20 cm are as follows: bulk density 1.3 g cm^{-3}, pH 8.4, organic matter 16.4 g kg^{-1}, total N 1.05 g kg^{-1}, available phosphorus (Olsen-P) 20.7 mg kg^{-1}, available potassium (NH_4OAc-K) 133.1 mg kg^{-1}, and mineral N 28.8 mg kg^{-1}.

2.2. Field experiments and crop management

Two experiments were performed to measure the N_2O emissions. In the first experiment (Exp. 1), three different mulching practices were examined using the same N fertilizer application rate (225 kg N ha^{-1}): a bare plot without mulching (BP, Fig. 1A), gravel mulching (GM, Fig. 1B), and plastic film mulching (FM, Fig. 1C). In the second experiment (Exp. 2), three different N application rates under plastic film mulching conditions were examined: no N applied (N0), N fertilizer applied at a rate of 225 kg N ha^{-1} plus manure (cow dung) applied at rate of 25 kg N ha^{-1} (N250), and N fertilizer applied at rate of 380 kg N ha^{-1} (N380). Each treatment involved alternating wide (60 cm) and narrow (40 cm) row spacing. The mulching treatments were manually mulched with gravel (2–4 cm in size) or plastic film. Each experiment was arranged in a completely randomized block design with three replicates, and the plot size was 56 m^2 (7 m × 8 m).

In the two experiments, N fertilizer in the form of urea (N 46%) was applied three times for all of the N-fertilized treatments. Forty percent of the N fertilizer was manually distributed over the soil surface prior to sowing and then plowed into the subsurface as a basal dressing. Thirty percent of the N fertilizer was applied at the jointing stage, and the remaining thirty percent was applied at the silking stage using a hole-sowing machine following precipitation. For each plot, 40 kg P ha^{-1} in the form of calcium superphosphate (P_2O_5 12%) and 80 kg K ha^{-1} in the form of potassium sulfate (K_2O 45%) were applied together with the basal N fertilizer. Manure for the N250 treatment was also applied prior to planting.

A high-yielding maize hybrid (Pioneer 335) was selected for use in this study. The plant density in Exp. 1 was 65,000 plants ha^{-1}, which was comparable to the densities in most farmers' fields (Chen et al., 2009), and in Exp. 2, the plant density was 85,000 plants ha^{-1}, which was determined using the Hybrid-Maize model (Yang et al., 2004) with the aim of obtaining a high grain yield. In each year, the maize was planted at the end of April and harvested at the end of September. During the maize growth season, there was no irrigation, and the soil water supply was solely dependent on natural rainfall for all of the treatments.

2.3. Measurement of N_2O emissions

Annual N_2O emissions were measured using the static chamber technique. Stainless steel base frames (50, 50 and 15 cm in length, width and height, respectively) were installed in the soil to a depth of 15 cm prior to planting (each covering half of the wide and narrow row spacing). A water channel was located at the top of the frame to seal the top chamber airtight during the sampling period (see Fig. 1). The top chambers were 50 cm length × 50 cm width × 50 cm height, and two small fans were installed at opposite positions at the top of each chamber to evenly mix the air inside the chamber. To minimize the air temperature changes inside the chamber, each side of the chamber was covered with a Styrofoam coating. Two maize plants were placed in each chamber area and cut to 50 cm in height to fit the height of the chamber when their stalks grew too high (in early July), but this cutting would not significantly affect the total seasonal N_2O emissions (Gao et al., 2014).

The N_2O emissions were measured every four and fifteen days during the maize growing (MS) and fallow season (FS), respectively. After the fertilization and precipitation events, gas samples were collected daily for ten days and four days, respectively. On each sampling day, the gas samples were collected between 8:30 a.m. and 11:30 a.m. using 50 ml polypropylene syringes equipped with 3-way stopcocks at 0, 10, 20 and 30 min after the chambers were closed. For the FM treatment in Exp. 1, the N_2O emissions and soil variables were only measured in 2012–2013.

The gas samples were analyzed on the sampling day using gas chromatography (Agilent 7890A, Shanghai, China) equipped with an electronic capture detector (ECD). The carrier gas was pure N_2 (99.999%) at a flow rate of 21 ml min^{-1}. The temperatures for the ECD detector and column oven were 300 and 60 °C, respectively. The N_2O emission rate was calculated from the linear increase in the concentrations in the chamber during the sampling period, and the cumulative emissions were estimated using linear interpolation. The yield-scaled N_2O emissions were calculated by dividing the annual N_2O emission by the maize grain yield.

2.4. Environmental and soil variables

The daily precipitation was recorded from an automatic weather station that was located approximately 50 m from our experimental field.

The soil temperatures at the surface and at a depth of 10 cm and the air temperature inside the chambers were measured using portable digital thermometers (JM624, Jinming Instrument Ltd., Tianjin, China) at the first and fourth sampling. The mean of the two readings represented the temperature of the sampling day. In the following analysis, we used the mean temperature of the two soil layers to represent the soil temperature for each treatment.