Field Crops Research 204 (2017) 1–11

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Effect of fertilizer N rates and straw management on yield-scaled nitrous oxide emissions in a maize-wheat double cropping system

Tao Huang[a,b,c,d], Hao Yang[a], Changchun Huang[a], Xiaotang Ju[d,*]

[a] *School of Geography Science, Nanjing Normal University, Nanjing 210023, China*
[b] *Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing Normal University, Nanjing 210023, China*
[c] *Jiangsu Provincial Key Laboratory of Materials Cycling and Pollution Control, Nanjing Normal University, Nanjing 210023, China*
[d] *College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China*

ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form
30 December 2016
Accepted 5 January 2017

Keywords:
Nitrous oxide
Nitrogen
Straw
Yield-scaled N_2O emission
North China Plain

ABSTRACT

Mitigating greenhouse gas emissions and ensuring crop productivity simultaneously is a major challenge that demands the balance of the amounts of nitrogen (N) and straw (S) applied to agricultural soil. This study seeks to determine whether higher grain yields and lower nitrous oxide (N_2O) emissions could be realized concomitantly by optimizing synthetic N rates and straw returning. The effect of fertilizer N rates and straw application on the inter-annual yield-scaled N_2O emission variations was measured over a three-year period (2011–2014) in a maize-wheat cropping system on the North China Plain (NCP). Yield-scaled N_2O emissions were expressed as g N_2O-N per Mg grain. Six treatments with three synthetic N levels (zero N [N_0], optimized N [N_{opt}] and conventional N [N_{con}]) and two straw management practices (straw removal [i.e., N_0, N_{opt} and N_{con}] and straw return [i.e., N_0+S, $N_{opt}+S$ and $N_{con}+S$]) were used. Optimized N (N_{opt}, $N_{opt}+S$) refers to the use of approximately 50% of the fertilizer N that is used in conventional farming practices (N_{con}, $N_{con}+S$), with no significant decrease in grain yields ($P > 0.05$). Optimized N reduced cumulative N_2O emissions by 18–37%, which in turn significantly decreased yield-scaled N_2O emissions by 38–42% ($P < 0.05$). The effects of fertilizer N rates and grain yields on cumulative N_2O emissions are described by linear and exponential models, respectively. Straw return had a positive effect on mean yield-scaled N_2O emissions both in the maize season and annually. Yield-scaled N_2O emissions are constructive considering the trade-off between grain yield and N_2O emission mitigation from intensive crop production. Optimized fertilizer N rate combined with straw return reduced yield-scaled N_2O emissions significantly in maize-wheat rotations.

1. Introduction

Nitrous oxide (N_2O) is a major greenhouse gas (GHG), increased to 319 ppb by 2005 from a pre-industrial concentration of 270 ppb (Butterbach-Bahl et al., 2013; IPCC, 2013). Agricultural soil is an important source of N_2O (Akiyama et al., 2010). Bouwman et al. (2002) estimated that 2.8 Tg N_2O are emitted from fertilized agricultural fields annually. Agricultural soil N_2O emissions are affected by environmental factors (climate, soil texture, soil organic carbon content, and soil pH), and by management factors (synthetic N, crop residue and manure application rates and types) (Bouwman et al., 2002; Butterbach-Bahl et al., 2013; Snyder et al., 2009).

Synthetic N application stimulates N_2O emissions by increasing substrate nitrification and denitrification. These are the main soil N_2O production processes (Snyder et al., 2009). Linear relationships between fertilizer N rates and direct N_2O emissions have been established (Liu et al., 2012; Mosier et al., 2006; Qin et al., 2012). Some studies even show an exponential relationship between them (Grant et al., 2006; Kim et al., 2013). The effect of crop residue return on soil N_2O emissions, however, is complex. In general, residue incorporation stimulates N_2O production because crop residue decomposition provides a substrate for nitrifiers/denitrifiers and promotes anaerobic conditions for denitrification (Huang et al., 2004; Huang et al., 2013). Nevertheless, straw return has either a negative effect or no significant effect on N_2O emissions, since higher C:N residue competes with nitrifiers/denitrifiers for available N (Ambus et al., 2001; Malhi et al., 2006). A meta-analysis found that the positive/negative effect of residue on N_2O emissions was highly dependent on its C:N ratio, soil moisture, soil texture, and soil pH (Chen et al., 2013). Yield-scaled N_2O emissions (expressed as g N_2O-N per Mg grain yield) are often proposed as a metric because of the important global challenge to ensure

---

[*] Corresponding author.
E-mail address: juxt@cau.edu.cn (X. Ju).

http://dx.doi.org/10.1016/j.fcr.2017.01.004
0378-4290/© 2017 Published by Elsevier B.V.

food security whilst reducing GHG emissions (Qin et al., 2012; Van Groenigen et al., 2010; Zhou et al., 2015; Li et al., 2015; Li et al., 2016). To our knowledge, few studies have investigated the interactions of fertilizer N rates and straw return on yield-scaled N_2O emissions (Ambus et al., 2001; Liu et al., 2014).

The North China Plain (NCP) is dominated by a maize-wheat double cropping system and produces the highest N_2O emissions per unit area of arable land in China. In the NCP, N fertilizer application rates are very high (263 and 325 kg N ha^{-1} for maize and wheat, respectively) (Gao et al., 2011; Ju et al., 2009). Researchers have recommended straw return to improve NCP soil fertility (Huang and Sun 2006). Earlier studies on the maize-wheat cropping system overestimated or underestimated yield-scaled N_2O emissions. They only measured N_2O for one or two years, which is not long enough to estimate annual N_2O emission rates accurately (Liu et al., 2011; Qin et al., 2012). Previous results were also based on yield-scaled N_2O emissions in single-maize (Adviento-Borbe et al., 2007; Mosier et al., 2006), double-rice (Shang et al., 2011), rapeseed-rice (Zhou et al., 2015), rice-wheat (Ma et al., 2013), and intensive vegetable (Li et al., 2015) cropping systems. Nevertheless, the existing literature did not indicate whether yield-scale N_2O emission measurements applied to maize-wheat cropping systems in long-term field trials.

The objectives of this study were to investigate the effects of synthetic N and straw return application rates on grain yield and N_2O emissions and to determine the best management system to reduce yield-scaled N_2O emissions.

2. Materials and methods

2.1. Description of study site

A field trial was started in October 2006 to study the effect of nitrogen- and carbon inputs on soil organic carbon (SOC) in maize (*Zea mays* L.) wheat (*Triticum aestivum* L.) crop rotation. The site has an altitude of 40 m and is located at the Shangzhuang Research Station (39°48′N, 116°28′E) of China Agricultural University in suburban Beijing. It has a typical sub-humid monsoon climate with an annual precipitation of 500–700 mm, of which 60–70% occurs between July and September. Fig. 1 shows the air temperature, soil temperature at 10 cm depth, precipitation, and irrigation rates from June 2011 to June 2014. The top 20 cm of the calcareous fluvo-aquic soil is 28% clay, 32% silt, and 40% sand. The pH is 8.1 (soil:water ratio 1:2.5). The bulk density is 1.31 g cm^{-3}, organic carbon content is 7.1 g kg^{-1}, total N is 0.8 g kg^{-1}, NO_3-N is 24.5 mg kg^{-1}, NH_4-N is 1.20 mg kg^{-1}, Olsen-P is 7.8 mg kg^{-1}, and available K is 76.2 mg kg^{-1}.

2.2. Experimental design

The trial consisted of six treatments with three N levels (zero-N, optimized N, and conventional N) with either crop residue removal (i.e., N_0, N_{opt}, and N_{con}) or crop residue return (i.e., N_0 + S, N_{opt} + S, and N_{con} + S). The design was a fully randomized block with three replicates. Each plot was 8 m × 8 m = 64 m^2. For N_{opt} in 2011 maize, N rates were estimated based on crop N demand (100 and 160 kg N ha^{-1} at the fourth- and tenth-leaf stage, respectively) and soil N supply (0–60 and 0–100 cm depth at the fourth- and tenth-leaf stage, respectively) synchronization (Zhao et al., 2006). After that, we modified N fertilizer rates to compensate for subsurface soil disturbances caused by preferential flow; as these perturbations affect soil core samples (Petersen et al., 2001). For maize, 65 kg N ha^{-1} was applied at both the fourth- and tenth-leaf stages. For wheat, both the basal and the top-dressed N fertilizer rate were 75 kg N ha^{-1}. In N_{con}, N fertilizer rates were based on NCP farming practices: for maize, 130 kg N ha^{-1} at both the four- and ten-leaf stages; for wheat, 150 kg N ha^{-1} as basal N fertilizer followed by plowing, then 150 kg N ha^{-1} at the shooting stage (Zhao et al., 2006). Details of the N fertilizer applications are shown in Table 1. For wheat, including the controls (N_0 & N_0 + S), basal phosphorus and potassium fertilizers were applied at 160 kg P_2O_5 ha^{-1} yr^{-1} and 90 kg K_2O ha^{-1} yr^{-1}. Other details are given in Qiu et al. (2012).

2.3. Field management

For maize (var. Zhengdan 958), row- and plant spacing were 60 cm and 25 cm, respectively. For wheat (var. Nongda 211), row spacing was 15 cm, and the sowing rate was 225 kg-ha^{-1}. The maize straw was cut by a corn harvester into 5–8-cm-long segments. The wheat straw was cut by a combine harvester into 2–5-cm-long segments. In the straw removal plots, all plants were manually cut and then removed. A mixture of dichlorvos and dimethoate (insecticides) was sprayed on both crops in mid-April, and again in mid- or late May. The herbicide acetochlor was sprayed after the maize was sown. The liquid pesticides were reapplied in early July. The solid granular pesticide carbofuran was applied to the top maize leaves in early August. Crop management dates and schedules are listed in Table 2. For other details, see our previous publication (Huang et al., 2013).

2.4. Grain yield measurement

Aboveground wheat biomass was harvested from an area measuring 9 m^2 (3 × 3 m) in the middle of each plot. Grain and straw samples were oven-dried at 60 °C and dry weights were determined. Maize was harvested from 14.4 m^2 (six rows 4 m in length) in the middle of each plot. Fresh ear- and stover weights were determined, and ears were counted. Five plants were randomly selected from the harvested maize, separated into grain, cob, and stalk, and oven-dried at 60 °C to determine dry weights. The nitrogen and carbon content of maize and wheat grain and straw were determined using a CN analyzer (Vario Max CN, Elementar, Hanau, Germany).

2.5. Nitrous oxide emission measurement

Nitrous oxide emissions were measured manually using the closed static chamber method. Before the maize was sown, two types of stainless steel base collar (60 × 50 cm and 50 × 30 cm, area = 0.3 m^2 and 0.15 m^2, respectively) were inserted 20 cm into the soil in each plot. The base collars were perforated (hole diameter = 5 cm) to ensure the flow of water and nutrients between the soil within and outside of the collar; thus, soil conditions in the chamber area were representative of those in the field. The collars stayed in place throughout crop rotation except during tilling. Type I chambers (60 × 50 × 50 cm) were used to measure N_2O emissions during the wheat season and the early maize stages (before the plants reached 50 cm). If the maize height surpassed 50 cm, type II chambers (50 × 30 × 20 cm) were used. They were vertically separated into two parts, and a hole (11 cm diameter) was drilled in the center of the top (Liu et al., 2012). Samples were taken between 8:00 a.m. and 11:00 a.m (Liu et al., 2010). Four gas samples were collected at 15-min intervals using a 50-mL plastic injector inserted into a three-way stopcock and a Teflon tube connected to the chamber. Daily measurements were carried out for about ten days after fertilizer application and for five days after rainfall or irrigation. Emissions were measured once weekly when the soil was frozen. At all other times, they were analyzed twice weekly.

Gas samples were analyzed for N_2O using a modified gas chromatograph (GC) (Agilent 6820, U.S.A.) fitted with a ^{63}Ni electron capture detector (ECD) operating at 350 °C. High-purity dinitrogen