Environmental Science and Pollution Research (2020) 27:43466–43479
https://doi.org/10.1007/s11356-020-09133-0

SUSTAINABLE WASTE TREATMENT AND MANAGEMENT

Evaluation of N_2O emission from rainfed wheat field in northwest agricultural land in China

Yue Yang[1] · Yan'an Tong[1] · Pengcheng Gao[1] · Yin Min Htun[1] · Tao Feng[1]

Received: 14 November 2019 / Accepted: 29 April 2020 / Published online: 16 May 2020

Abstract

The net greenhouse gas (NGHG) emissions and net greenhouse gas intensity (NGHGI) were investigated via the determination of nitrous oxide (N_2O) emission in loess soil under rainfed winter wheat monocropping system during 3 years of field study in Northwest China. Five treatments were carried out: control (N_0), conventional nitrogen (N) application (N_{Con}), optimized N application with straw (SN_{Opt}), optimized N application with straw and 5% of dicyanodiamide (SN_{Opt} + DCD), and optimized N rate of slow release fertilizer with straw ($SSRF_{Opt}$). Over a 3-year period, the NGHG emissions were achieved 953, 1322, 564, and 1162 kg CO_2-eq ha^{-1}, simultaneously, and the NGHGI arrived 158, 223, 86, and 191 kg CO_2-eq t^{-1} grain in N_{Con}, SN_{Opt}, SN_{Opt} + DCD, and SSR_{Opt} grain, respectively. Contrasted with conventional farming system, optimized farming methods reduced 32% of N fertilizer use without significant decrease in grain yield, but brought about 38% increase in N_2O emissions, up to 28% gained in soil CH_4 uptake. Thus, it was observed that the straw incorporation performs noticeable increased in N_2O emissions in the winter wheat cropping season. Among the optimized N fertilizer rates compared with the SN_{Opt} treatment, the SN_{Opt} +DCD and SSR_{Opt} treatments decreased in N_2O emissions by approximately 55% and 13%, respectively. Additionally, the N_2O emission factor across over a 3-year period was 0.41 ± 0.08% derived from N fertilizer, and it was half of IPCC default values for upland corps. It is expected possibly due to low precipitation and soil moisture with the monocropping system. The 25% higher in the amount of rainfall (almost 300 mm in 2013–2014) during a cropping season underwent into 1–2-fold increase in N_2O emissions from N-fertilized plots. As the statistical differences among annual cumulative emissions coincided with that during winter wheat growing season, it can be concluded that crop growing season is a vital important period for the determination of N_2O emissions from under rainfed monocropping system.

Keywords N_2O emission · Straw return · Rainfed · Nitrification inhibitor · Slow release fertilizer

Highlights

- N_2O emission was measured from rainfed wheat field in northwest agricultural land in China.
- N_2O emission related with conventional nitrogen (N) application and optimized N application with straw.
- Application of conventional nitrogen increased N losses and N_2O emissions.

Responsible editor: Philippe Garrigues

✉ Yan'an Tong
tongyanan@nwafu.edu.cn

✉ Pengcheng Gao
Pengcheng1969@nwsuaf.edu.cn

[1] College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, China

Introduction

Nitrogen fertilizer input in China's agricultural production is large, which not only consumes huge wealth but also brings huge environmental risks due to the low nitrogen utilization rate in the current season. A large part of it is discharged into the atmosphere in the form of ammonia and N_2O, becoming a major source of agricultural non-point source pollution (Yang et al. 2015b; Yang et al. 2020a). As reported by Vilarrasa-Nogué et al. (2020), agriculture attributed to 10–12% of global man-made greenhouse gas (GHG) emissions. The N_2O emissions from croplands are strongly controlled by (1) environmental factors such as atmospheric temperature, relative humidity, and precipitation (IPCC 2013); (2) soil edaphic properties such assoil temperature and water content as well as availability of mineral nitrogen etc. (Hu et al. 2013); and (3) agricultural resource such as nitrogen and manure utilization, tillage management, straw application, and also crop rotations (Qin et al. 2012; Yang et al. 2020a; Cheng et al. 2020).

Since 1990s, the overuse and the influence of nitrogen fertilizer application in China were begun to emerge on the ecological implications and the reason for nitrogen use (Kahrl et al. 2010). According to achievements from numerous researches, the range of 150–200 kg N ha^{-1} is considered the optimum yield of food crops in China (Xin et al. 2019). On the other hand, in past decades, straw produces reached hundreds of million tons per year in China (Yang et al. 2015b), and most farmers burn straw in their fields to reduce processing time and costs. Straw mulching for power generation faces a series of technical, economic, and management problems and risks. Straw mulching is an appropriate and effective treatment channel to alleviate the negative effects of straw mulching (Lu et al. 2010; Xin et al. 2019).

In addition, the study of long-term field has shown that application of suitable fertilizer and straw mulching could promote soil organic carbon content (Huang et al. 2013a; Yang et al. 2020b; Yang et al. 2020c). However, these measures might also give impetus to N_2O emissions via the elevation of soil nitrifier and denitrifier substrates simultaneously (Zhang et al. 2019; Vilarrasa-Nogué et al. 2020). Furthermore, straw return increases annual mean N_2O emissions by 27.9% from field research in suburban Beijing (Huang et al. 2013b). However, crop residue return has several advantages to increase carbon (C) sequestration in soil (Zhang et al. 2010; Huang et al. 2013a; Yang et al. 2020a) followed by increasing grain yields (Cheng et al. 2020), but some researches showed no impact on crop yield (Qiu et al. 2012). Qiu et al. (2015) reported the reverse effect of adding plant-derived dissolved organic matter (DOM) increased the carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions, and accelerated the decomposition of soil organic carbon, as well as reduced the soil carbon sink. Therefore, it is very essential to evaluate the net mitigation effect based on greenhouse gas emission response of straw mulching.

In order to minimize the gaseous emission from farmland in China, the optimal nitrogen application should be adopted first (Shi et al. 2014; Yang et al. 2019a) and, secondly, applied mixture and synthetic fertilizers with nitrification inhibitors (Akiyama et al. 2010); then, slow release fertilizers should be considered (Jiang et al. 2010; Huang et al. 2013b). Due to the inhibition of the first stage of nitrification (NH_4^+ oxidation to NO_2^-) by suppressing the bacterial enzyme activities, the 10% use of DCD reduced N_2O emission 42–82% and also can increased herbage production (Gillette et al. 2018; Thers et al. 2020). The slow release fertilizer (SRF) could promote the nitrogen uptake efficiency and increase the crop yields in several production systems. The results by Geng et al. (2015) stated that the seed cotton yields in the SRF treatments were increased by 15–18% compared with urea application from cotton production in China. Besides, the slow release fertilizers also contribute towards environmental pollution control by means of the mitigation of hazardous GHG emissions and water eutrophication (Trinh et al. 2015; Yang et al. 2019b).

Although the greenhouse gas emission scale and worldwide distribution from natural to agricultural were estimated, the emission fluxes of Chinese rainfed soil condition under monocropping systems in Northwest China region are still poorly defined. China has 57.6 million hectares of dry land, about 4% of the world's total arable land (Cheng et al. 2020). The arable lands from the Northwest China obtained resembling climatic condition with the Northern China Plain. The unique planting system in this region is irrigation rotation between winter wheat and summer maize, and monocropping with winter wheat or maize also occurred under rainfed farmland (Yang et al. 2015b). Campanha et al. (2019) pointed out the N_2O emission is non-significantly distinct between irrigated soil and rainfed sandy loam in semi-arid areas of northwest Kenya.

However, the precipitation instead of irrigation may become a vital additive factor controlling net greenhouse gas (NGHG) emission and net greenhouse gas intensity (NGHGI) in rainfed monocropping system. The unique characteristics of soil and climatic conditions associated with winter wheat monocropping system under rainfed condition became attractive to examine the dynamics in GHG emissions correlated by optimized handling approach. Therefore, present investigation aimed (i) to study the influential factors on N_2O emissions and consequential factors affecting NGHG emission as well as NGHGI under rainfed farmland, (ii) to evaluate the value of precipitation in terms of climate change governed on N_2O emission fluxes within the cropping cycle, and (iii) to anticipate a better agricultural management practice that can reduce NGHG emissions with maintained or increased grain yields under rainfed monocropping systems.

Materials and methods

Study site description

A experiment of a 3-year field begun at wheat growing season in October 2012 and ended in July 2015. This research experiment center site is located in Chinese National Soil Fertility and Fertilizer Efficiency Monitoring Base of Loess Soil in Wuquan Town, Yangling District, Shaanxi Province, Northwest China. In this site, the soil type was loess soil comprising 32% of clay, 52% of silt, and 16% of sand. The content of soil organic matter, total N, and Olsen-P were 17.1 g kg^{-1}, 0.93 g kg^{-1}, and 15.0 mg kg^{-1}; exchangeable K was 191 mg kg^{-1} with pH 7.44 across all plots. Temperature and precipitation were 12.9 °C and 550 mm, in which the precipitation is mainly achieved from July to September.

Experimental design and field management

In this study, there were five treatments and they were no N application as control (N_0), conventional N management (N_{Con}), optimized N management (SN_{Opt}) in which its distinct characteristic was an optimized N rate for crop coupling with straw incorporation, optimized N management adding 5% of dicyanodiamide (DCD) as nitrification inhibitor (SN_{Opt} + DCD), and optimized N management of slow released fertilizer ($SSRF_{Opt}$). It was conducted under completely random block design with three replications, and each plot was 30 m^2 (for 6 m long and 5 m wide). The type of *Triticum aestivum* L. cv. *Xiaoyan* 22 was main winter wheat and planting according to 120 kg ha^{-1} sowing rate and the row spacing of 20 cm. All fertilizers were applied as basal fertilizer. For N_{Con}, the fertilizer application amount was 220 kg N ha^{-1}, with local conventional fertilization method, and the optimized N rates for SN_{Opt}, SN_{Opt} + DCD, and $SSRF_{Opt}$ treatments were 150 kg N ha^{-1} which was estimated in line with crop nitrogen demand. Urea (46% N) fertilizer was the main source of N fertilizer except for SRF in this study. Phosphorus fertilizer (superphosphate) was utilized with the rates of 90 kg P_2O_5 ha^{-1} in each treatment, and the rates of potassium fertilizer (potassium sulfate) to be applied were calculated due to that contained in SRF as 47 kg K_2O ha^{-1}. Due to NPK composition ratios (26:6:8) in SRF, it was calculated to reach optimized N content of 150 kg N ha^{-1} and then added a required amount of P_2O_5 for the $SSRF_{Opt}$ treatment. The planting system in this area is winter wheat-summer maize irrigation system. This experiment was performed under rainfed wheat-summer fallow monocropping system. In addition, weeding was carried out manually during vegetative growth stages in the spring and rouging before harvest.

Greenhouse gas emission measurements

N_2O emission and CH_4 uptake were in three winter wheat cultivation cycles from 2012 to 2015; closed static chamber method was used for manual measurement (Mosier et al. 2006). Stainless steel base rings (50 × 50 × 20 cm) are inserted into the soil in each plot before planting the wheat. They were removed and reset again only once in a year at the period of tillage for winter wheat. In order to collect samples, the chambers (50 × 50 × 50 cm) were set onto the base collars adding some water to ensure air-tight condition. Immediately after the chamber was enclosed, the initial air sample was obtained from the top of the chamber by using a plastic syringe (50 mL) through a three-way value and a ptfetube connected with the chamber. In total, four samples were obtained from each treatment at 0, 15, 30, and 45 min with time intervals of 15 min. Daily and frequent measurements were carried out after fertilizer application and precipitation. The time of collecting air was 08:30–11:00 am of local time to obtain more representative results of gas emission fluxes.

An improved gas chromatograph (Agilent, 7890A, USA) equipped with a ^{63}Ni-electron capture detector (ECD) operating at 350 °C was adopted. High-purity nitrogen and 10% CO_2 as the supporter and complementary gas for N_2O analysis (Zheng et al. 2008) were used. Calibration was performed by standard calibration gases before each measurement was performed, and air conditioning was used in the laboratory to stabilize the temperature at the time of measurement to decrease the tendency of ECD to change with temperature. In order to calculate the N_2O emission flux, linear regression or non-linear method was used to calculate the N_2O flux according to the variation rule of the concentration of the air volume above the closed chamber. It is calculated through Eq. (1) below.

$$F = k_1 \times 273/(273 + T) \times M/V \times \mathrm{H} \times dc/dt \quad (1)$$

$$c = a + bt \; (dc/dt = b) \quad (2)$$

$$c = a + bt + dt^2 \; (dc/dt = b) \quad (3)$$

where F (μg N_2O–N m^{-2} h^{-1} or μg CH_4–C m^{-2} h^{-1}) is the net flux; $k_1$is the dimensional conversion factor (0.001); and T (°C) presents the average temperature of the room. M (28 g or 12 g of N_2O–N mol^{-1} and CH_4–C $mol^{-1}$for N_2O or CH_4) is the molecular weight of N_2 in the N_2O, C in CH_4; V is the volume of mole (22.4 L mol^{-1}); H (m) is the height of chamber and c (μL L^{-1}) is the mixing volume ratio of nitrous oxide and methane; t (h) is the chamber closing time; dc/dt (μL L^{-1} h^{-1}) is the initial rate of changes in concentration for N_2O or CH_4 in the gas chamber; and a, b, and d are the parameters obtained by fitting the linear or non-linear change function of concentration with time (Gao et al. 2014). The fluxes of N_2O and CH_4 are expressed as the average of three repeated measurements.

Estimation of N_2O emission

By adding up the daily fluxes of the sampled and non-sampled days, the annual cumulative N_2O emissions were calculated, and then, the linear interpolation between the time intervals was used for estimation (Mosier et al. 2006). The NGHG emissions and NGHGI were estimated and calculated in line with Eqs. (4) and (5). Additionally, the N_2O emission factor (EF) derived from N fertilizer was determined by mean of Eq (6).

$$\mathrm{NGHG} = \mathrm{N_2O{-}N} \times 44/28 \times 298 + \mathrm{CH_4{-}C} \times 16/12 \times 25 \quad (4)$$

where N_2O–N and CH_4–C units are kilograms of N_2O–N per hectare and kilograms of CH_4–C per hectare, respectively. NGHG was calculated by CO_2 equivalent (CO_2-eq). In the 100-year time range, 1 kg of N_2O and CH_4 are equal to 298 and 25 kg of CO_2 respectively for the global warming potential (Forster et al. 2007).

$$\mathrm{NGHGI} = \mathrm{NGHG}/\mathrm{grain\ yield} \tag{5}$$

where grain yield unit is tons per hectare.

$$\mathrm{EF} = \frac{\sum(\mathrm{N_2O{-}amendment}) - \sum(\mathrm{N_2O{-}control})}{\mathrm{Total\ Input\ N}} \times 100\% \tag{6}$$

where EF is the N_2O emission factor (N_2O–N emission as a percentage of N application); N_2O-amendment and N_2O-control are the cumulative N_2O emissions from the N application and the plots of control, respectively (kg N_2O–N ha^{-1}); and total input N is the amount of N fertilizer applied (kg N ha^{-1}).

Soil analysis

Soil temperature (10 cm of topsoil) and indoor air temperature were measured by digital thermometer immediately before and after collecting air samples. To measure soil moisture contents, samples were collected at 0–20 cm of top soil in each plot, and about 20 g of soils was dried in an oven at 105 °C for 24 h. The soil water-filled pore space (WFPS) was estimated by Eq. (7).

$$\mathrm{WFPS} = \frac{\mathrm{Soil\ water\ content\ (\%)} \times \mathrm{Soil\ bulk\ density}}{1 - \frac{\mathrm{soil\ bulk\ density}}{2.65} \times 100\%} \tag{7}$$

Grain yield and N use efficiency

A representative sampling area of 1 m^2 was assigned in each plot to harvest for wheat grain yield and harvest index (HI). The dry weights of straws were measured as above ground biomass, and the wheat grain yield was recorded at approximately 15% moisture content in grain. The N use efficiency (NUE) % was estimated by Eq. (8) as described by Ladha et al. (2005).

$$\mathrm{NUE} = \frac{\sum(\mathrm{Plant\ N{-}amendment}) - \sum(\mathrm{Plant\ N{-}control})}{\mathrm{Total\ Input\ N}} \times 100\% \tag{8}$$

where NUE is the N use efficiency (%); plant N-amendment and plant N-control are the accumulative N uptake by plant (N from grain + N from straw) at harvest from the N application and control plots, respectively; and total input N is the rate of N fertilizer applied (kg N ha^{-1}).

Statistical analysis

The raw data was calculated by Microsoft Excel 2010 spreadsheet. The difference among treatments was examined via ANOVA and the Sigma plot 12.5 (Syst at Software Inc., Erkrath, Germany) was used to compare the mean to calculate the minimum significant difference (LSD) at the 5% level and to draw a chart.

Results

Precipitation, soil temperature, and soil WFPS percentage

The temperature of air and 10 cm of topsoil as well as the precipitation during the study period are presented in Fig. 1. The precipitation obtained was 233.2 mm and 225.8 mm in 2012–2013, 296.3 mm and 398.8 mm in 2013–2014, and 237.0 mm and 283.8 mm in 2014–2015, respectively, during wheat growing and fallow season (Table 1). The relatively largest quantity of total precipitation occurred in 2013–2014 cropping cycle during this study. Temperature for 10 cm of topsoil varied with daily mean atmospheric temperature, and it ranged from − 1.2 to 30.0 °C with mean value of 14.4 °C. Although soil temperatures at 10 cm depth were certainly similar between straw and without straw management condition, surface soil temperatures under without straw return treatment relatively reflected to atmospheric temperature rather than those under straw return (data are not shown). It was observed that straw could maintain surface soil temperature warmer in winter as well as could somewhat reduce surface soil temperature in summer. As this field research was done under rainfed dryland, soil WFPS in 20 cm of topsoil was enhanced by precipitation and declined by evaporation and other physiological processes (Fig. 2). In this study, soil WFPS% at each sampling point was below 60%, i.e., the highest value of WFPS% was 55.99% and the lowest was down to 6.98% during July drought.

N_2O emissions from soil

The fluxes of N_2O emission for all treatments from October 2013 to September 2015 are shown in Fig. 3. The mean values of N_2O emission fluxes varied from − 5.49 to 281.91 μg N_2O–N m^{-2} h^{-1} throughout this study. The largest gap of the N_2O emissions occurred as ranging from − 22.91 to 456.07 μg N_2O–N m^{-2} h^{-1} in 2013–2014 winter wheat growing season due to greater quantity of precipitation. The relatively higher peaks of emission were observed within one and half months after basal fertilization in each circle, and some differences were significant among the treatments during the periods. Then, the emission was slightly low with lower temperature in the winter. The highest N_2O emissions were produced from the SN_{Opt} treatment during few days after fertilization, and the maximum peaks of mean emissions were detected in 5 November 2013 (20 days after basal fertilization) with 281.91 μg N_2O–N m^{-2} h^{-1} and in 29 October 2014 (13 days

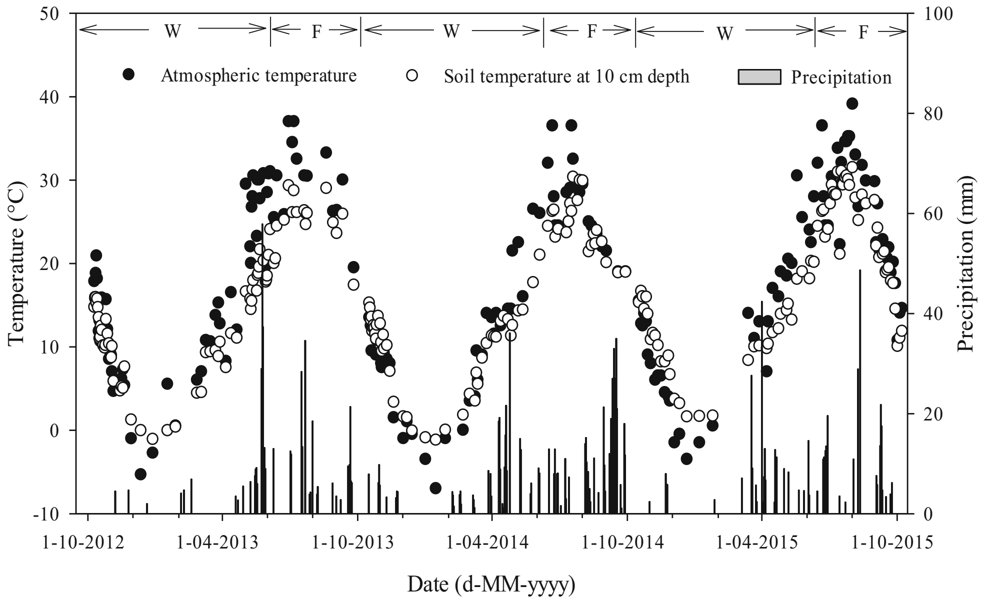

Fig. 1 Atmospheric temperature (°C), soil temperature at 10 cm depth (°C), and precipitation (mm) during field study. Wheat cropping season and fallow season are denoted by W and F, respectively

after basal fertilization) with 84.27 μg N_2O–N m^{-2} h^{-1}, in first, second, and third cycles, respectively. As this study was done in rainfed field, some small peaks of N_2O fluxes were formed in spring before wheat was harvested and in the fallow season of summer associated with warmer temperature and frequent precipitation.

The mean cumulative N_2O emissions were ranging from 0.36 to 0.60, 0.44 to 1.60, and 0.15 to 1.11 kg N_2O–N ha^{-1} $year^{-1}$ in 2012–2013, in 2013–2014, and in 2014–2015, respectively (Table 2). The values of annual cumulative N_2O emissions in 2013–2014 were relatively the largest among a 3-year investigation. However, the similar trends of results on cumulative N_2O emission through different management practices were observed in later 2 years, i.e., the annual cumulative N_2O emission by all treatments was in the order of SN_{Opt} > $SSRF_{Opt}$ ≥ N_{Con} > SN_{Opt} + DCD ≥ N_0 treatments, with an exception of first year comprehending without any significant difference among the treatments. In fact, N_2O emissions during the fallow season had no significant difference (ranged of 0.14–0.33 kg N_2O–N ha^{-1}) among the treatments over a 3-year field study, regardless of the amount of precipitation obtained (Table 1). In 2013–2014 and 2014–2015 cropping season, compared with the N_{Con} treatment, cumulative N_2O emissions were increased about double in the SN_{Opt} treatment, whereas the SN_{Opt} + DCD and $SSRF_{Opt}$ treatments decreased N_2O emissions with 72–86% and 11–39% compared with SN_{Opt} among straw return treatments. The N_2O emission factors (EF) derived from N fertilizer were ranging from 0.03 to 0.76% in this study (Table 2). Due to highest rainfall obtained in 2013–2014, the highest EF which was almost double of that over a 3-year period was observed. Among them, the lowest value was determined in the SN_{Opt} + DCD treatment, and the highest value occurred in

Table 1 Comparison of cumulative N_2O emission by each treatment as associated with precipitation observed in winter wheat-summer fallow monocropping system under rainfed. The number represents mean ± standard error ($n = 3$); different letters within same column indicate significant differences ($p < 0.05$)

Impacts	2012–2013		2013–2014		2014–2015	
	Winter wheat	Fallow	Winter wheat	Fallow	Winter wheat	Fallow
Precipitation (mm)	233.2	225.8	296.3	398.8	237.0	283.8
N_2O emission (kg ha^{-1})						
N_0	0.21 ± 0.12a	0.16 ± 0.06a	0.29 ± 0.06a	0.14 ± 0.06a	0.13 ± 0.11ab	0.16 ± 0.01a
N_{Con}	0.37 ± 0.16a	0.19 ± 0.03a	0.67 ± 0.22ab	0.33 ± 0.09a	0.37 ± 0.06bc	0.29 ± 0.07a
SN_{Opt}	0.36 ± 0.07a	0.16 ± 0.01a	1.37 ± 0.61b	0.21 ± 0.09a	0.73 ± 0.17d	0.22 ± 0.05a
SN_{Opt} + DCD	0.21 ± 0.07a	0.20 ± 0.02a	0.38 ± 0.08a	0.26 ± 0.13a	0.10 ± 0.07a	0.24 ± 0.10a
$SSRF_{Opt}$	0.31 ± 0.18a	0.19 ± 0.07a	1.22 ± 0.06b	0.26 ± 0.06a	0.44 ± 0.08c	0.23 ± 0.02a

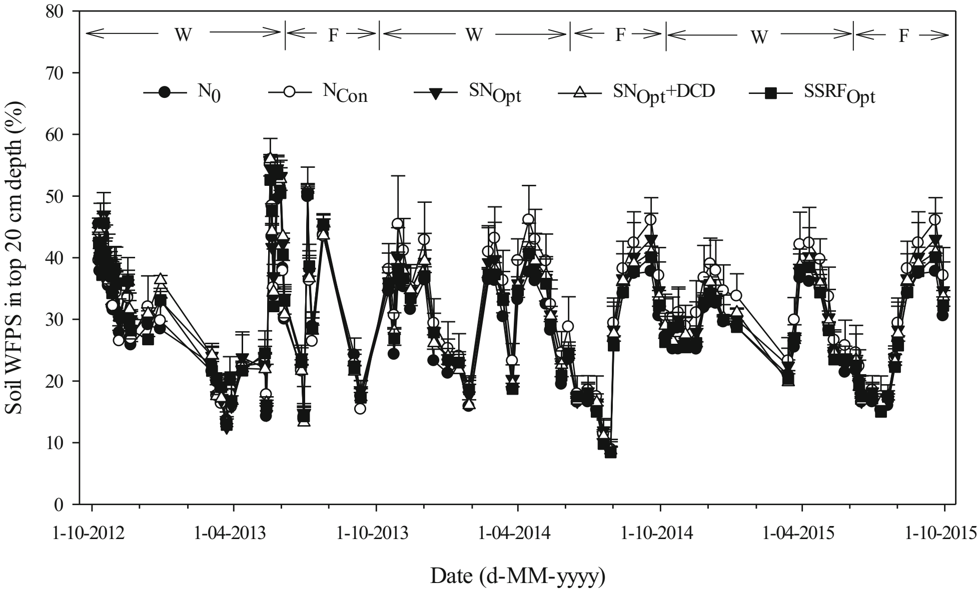

Fig. 2 Dynamic of soil water-filled pore space (WFPS%) in the top 20 cm depth of soil during the study period under rainfed: Wheat cropping season and fallow season are denoted by W and F, respectively; error bars represent standard deviation of the mean ($n = 3$)

the SN_{Opt} treatment. Additionally, the EF of the N_{Con} treatment was greater than that of the $SSRF_{Opt}$ treatment.

NGHG emission and NGHGI

The CH_4 is very small sink for dry cropland in China northern plain, and CH_4 uptake makes partial contribution when calculating the net global warming potential (NGWP) from all emission and sinks (Huang et al. 2013b). Mean atmospheric CH_4 uptake by soil was approximately 7 and 14 μg CH_4–C m^{-2} h^{-1}in 2013–2014 and 2014–2015, respectively. No significant difference on either daily or annual CH_4 uptakes by soil was found among the treatments (Fig. 4). The mean annual CH_4 uptakes by soil were ranging from 0.96 to 1.36, 0.33 to 0.69, and 0.98 to 1.31 kg CH_4–C ha^{-1} $year^{-1}$in 2012–2013, 2013–2014, and 2014–2015, respectively (Table 3). In this study, it was discovered that soil CH_4 uptakes were decreased by higher precipitation in 2013–2014. These values were very close to the uptake of 0.9 (Hu et al. 2013) and 1.1 to 1.3 kg CH_4–C ha^{-1} $year^{-1}$ (Gao et al. 2014).

The NGHG and NGHGI are exhibited in Table 3. NGHG of the SN_{Opt} treatment was the highest and about 39% higher than that of the N_{Con} treatment over the 3-year period while it was 57% higher in 2013–2014 and 48% in 2014–2015 although NGHG of straw management treatments (SN_{Opt}, SN_{Opt} + DCD, and $SSRF_{Opt}$) did not increase compared with conventional practice (N_{Con}) in the first year 2012–2013. On the other hand, compared with the SN_{Opt} treatment among straw management practices, NGHG of SN_{Opt} + DCD and $SSRF_{Opt}$ were reduced by approximately 26% and 1% in 2012–2013, 59% and 5% in 2013–2014, and 70% and 31% in 2014–2015, respectively, while they were decreased by 57% and 12%, respectively, over a 3-year period. Similarly, the NGHGI was reduced by 61% and 14% in the SN_{Opt} + DCD and $SSRF_{Opt}$ treatments, respectively, compared with SN_{Opt} among straw return treatment which has the highest increase of NGHGI withstanding 41% higher than the N_{Con} treatment over a 3-year period.

Wheat grain yield

As there was no N fertilizer for the N_0 treatment, the mean of winter wheat grain yields for N_0 was significantly low at 3.84, 4.72, and 4.26 t ha^{-1} in 2013, 2014, and 2015, respectively (Table 3). The grain yields of the other treatments were not significantly different in this study, except in 2013, SN_{Opt} + DCD produced significantly higher yield than the N_{Con} treatment. The grain yield of the SN_{Opt} + DCD treatment always showed the highest in each cropping cycle by 6.26, 6.70, and 6.59 t ha^{-1} in 2013, 2014, and 2015, respectively. Overall, when the mean N use efficiency (NUE) affected by the treatments was compared over a 3-year study, it was observed that the SN_{Opt} + DCD treatment had the highest N use efficiency with 33.5%, followed by the N_{Con} treatment with 32.4%, $SSRF_{Opt}$ with 29.4%, and SN_{Opt} with 27.7%, respectively (Table 2).

Discussion

N_2O emissions from rainfed drylands by monocropping system

The patterns and processes of N_2O emissions have been explained by several studies that N_2O emission peaks can occur within 1 or 2 weeks after N fertilizer application and irrigation

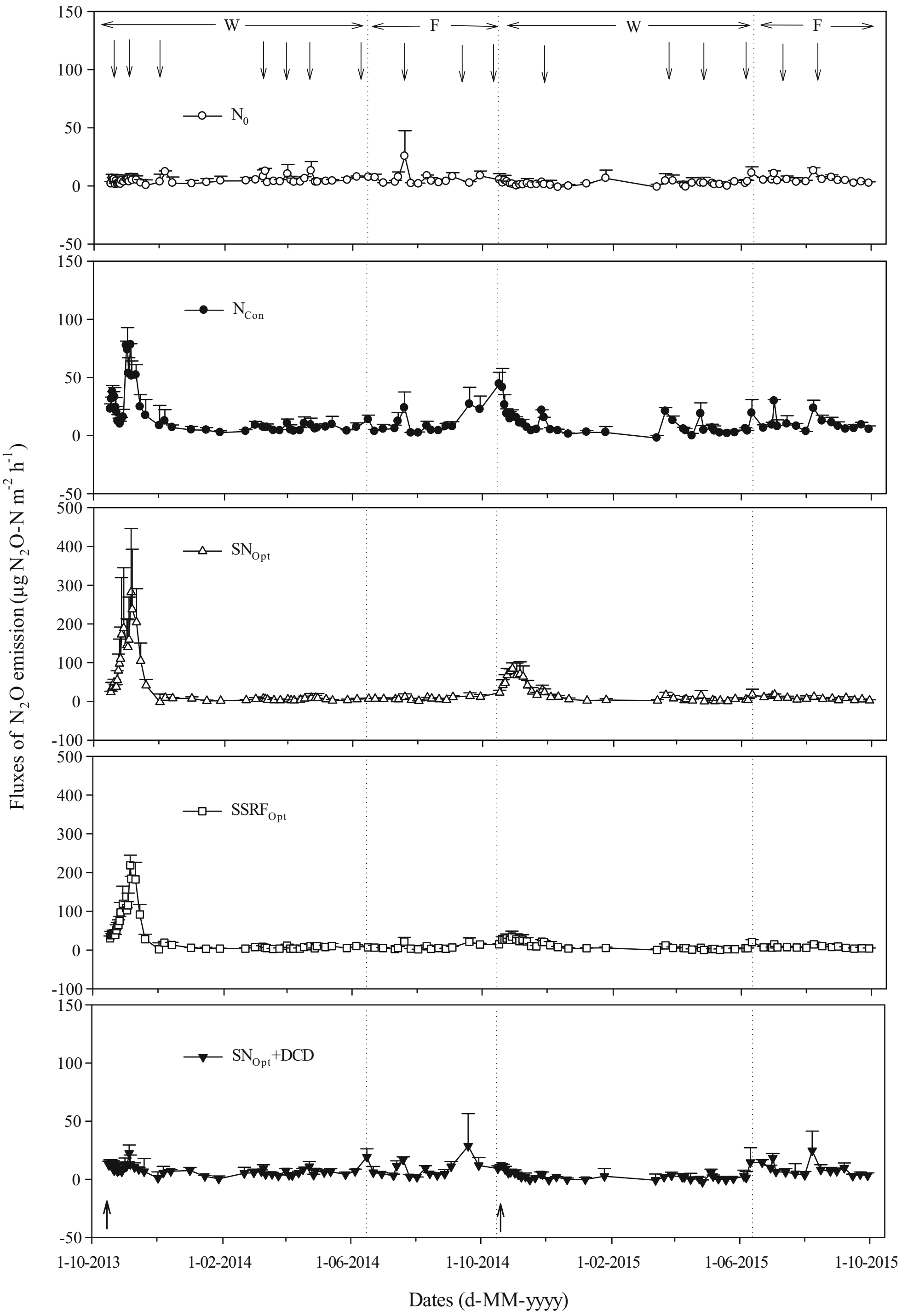

Fig. 3 Mean N_2O emissions from winter wheat-summer fallow cropping system under rainfed: Wheat cropping season and fallow season are denoted by W and F, respectively; error bars represent standard deviation of the mean ($n = 3$); upward line arrows indicate basal fertilizer application and straw dressing for winter wheat; downward arrows indicate remarkable precipitation (≥ 8 mm) during this study

or rainfall combined with high soil temperature and moisture content (Cui et al. 2012; Hu et al. 2013; Huang et al. 2013b). The N_2O emission fluxes were mainly attributed by N fertilizer application throughout this study, and our results fell well within the range reported by those earlier studies. Annual cumulative N_2O emissions were ranging from 0.29 to 1.64 kg N_2O–N ha^{-1} and in line with the result of 0.20 to 4.54 kg N_2O–N ha^{-1} from double-cropping cereal rotation system in North China plain (Huang et al. 2013a). In our study, the cumulative N_2O emissions during the fallow seasons under a 3-year field experiment vacillated from 0.14 to 0.33 kg N_2O–N ha^{-1}without any significant difference among the treatments no matter what the temperatures, soil moisture, and frequency and amount of rainfall were. The emissions from fallow land by treatment without N fertilizer application could be reduced from 5 to 25% in 2012–2013, 47 to 130% in

Table 2 N_2O emission factor derived from N fertilizer and N use efficiency depended upon different management practices. The different letters within same column indicate significant differences ($p < 0.05$)

Treatments	Input N (kg ha^{-1})	N_2O emission factor derived from N fertilizer (%)				Plant uptake N (kg ha^{-1})*	N use efficiency (%)*
		2012–2013	2013–2014	2014–2015	Over 3 years		
N_0	0	-	-	-	-	52.9 ± 2.9	-
N_{Con}	220	0.09a	0.25a	0.17ab	0.17ab	124.1 ± 14.5	32.4
SN_{Opt}	150	0.11a	0.76b	0.45c	0.44b	94.4 ± 2.8	27.7
SN_{Opt} + DCD	150	0.03a	0.14a	0.04a	0.07a	103.2 ± 4.0	33.5
$SSRF_{Opt}$	150	0.09a	0.69b	0.26b	0.35ab	97.0 ± 20.3	29.4

*Average values of 3 years

2013–2014, and 45 to 88% in 2014–2015, respectively, compared with treatments with N fertilizers. It would be because the availability of soil mineral N (NO_3^-–N and NH_4^+–N) in N-fertilized soil was slightly higher than that in soil without N fertilizer.

However, soil mineral N content with N_2O emissions were not presented with significant correlation in the present study and it was granted by Gao et al. (2014). On the other hand, the mean values of N_2O emission fluxes from our rainfed field ranging from 10 to 25 μg N_2O–N m^{-2} h^{-1}in the winter wheat cropping season were slightly lower than those from 15 to 30 μg N_2O–N m^{-2} h^{-1}from irrigated winter wheat in North China plain by Gao et al. (2014). The cumulative N_2O emissions during the winter wheat cropping season except in 2012–2013 had significant differences among the treatments depending mainly upon straw incorporation, amount of precipitation, and rates and types of N fertilizers including nitrification inhibitor. Compared with treatment without N fertilizer, the cumulative N_2O emissions were 1–5 times increased by N fertilization and straw incorporation. More than half of annual cumulative N_2O were emitted during the winter wheat cropping season and the similar statistical differences of annual emissions occupied in this period. It indicated that cropping season plays as a responsible period for the investigation of N_2O emissions since the effectiveness of different management practices on emissions were mainly observed during the winter wheat cropping season (Tables 1 and 3).

In this study, the N_2O emission factor derived from N fertilizer varied from 0.03 to 0.76% with the mean value of 0.40 ± 0.08% due to the different managements. This is well below the default emission factor, but within the range of fertilized fields in Canada, it is 0.03–1.45% (Ma et al. 2010), near the ranges from upland in China with 0.40–1.54% (Shepherd et al. 2015), and from unplanted and planted soil in China with 0.19 to 0.3% (Ni et al. 2012). In general, N_2O emissions are typically based on the IPCC's 2006 default emission factor, which is 1% of the amount of nitrogen applied to mineral fertilizers, manure, and crop residues (Zhang et al. 2019). The starting point for this method was a 2-year monitoring study of Velthof in which the emission factor of grassland on sandy soil with calcium ammonium nitrate was exactly 1%. However, there are significant differences in N_2O emission factors due to distinct environment conditions, crops (grassland, cultivated land, crop residues), and management (fertilizers and fertilizers, application amount, application time) (Badagliacca et al. 2018; Campanha et al. 2019; Thers et al. 2020). However, Gillette et al. (2018) indicated the lower emission factor by 0.02% from a rainfed cropped soil in a semi-arid region.

Factors regulating N_2O emission under rainfed with winter wheat-summer fallow monocropping system

N_2O emission from rainfed dryland is weather-dependent as the annual N_2O emissions from rainfed winter wheat monocropping system were largely correlated to the annual mean of daily maximum air temperature, annual rainfall, and the rates of N fertilizer application (Zhang et al. 2019; Campanha et al. 2019). In this study, we could not find significant relationship among soil temperature, WFPS, and N_2O emission, and the similar result was reported by Gao et al. (2014). On the other hand, some scientists reported that N_2O emission was closely influenced by rainfall if it is above 40 mm (Ma et al. 2010; Liu et al. 2011). Although some small peaks of N_2O emission fluxes without any significant difference were performed during the fallow seasons associated with warmer temperatures and precipitation, the remarkable differences of emissions among the treatments were observed during winter wheat cropping seasons. In that periods, compared with control (N_0) treatment, the mean cumulative N_2O emissions from N-fertilized treatments of N_{Con}, SN_{Opt}, and $SSRF_{Opt}$ except SN_{Opt} + DCD were significantly increased by 1.3 times, 3.6 times, and 3.2 times in 2013–2014, and by 1.8 times, 4.6 times, and 2.4 times in 2014–2015, respectively. Unfortunately, we could not find any significant difference for N_2O emissions among the treatments in the first cropping cycle 2012–2013, but compared with N_0 treatment emissions, they increased by 78%, 75%, 2%, and 49% from the N_{Con},

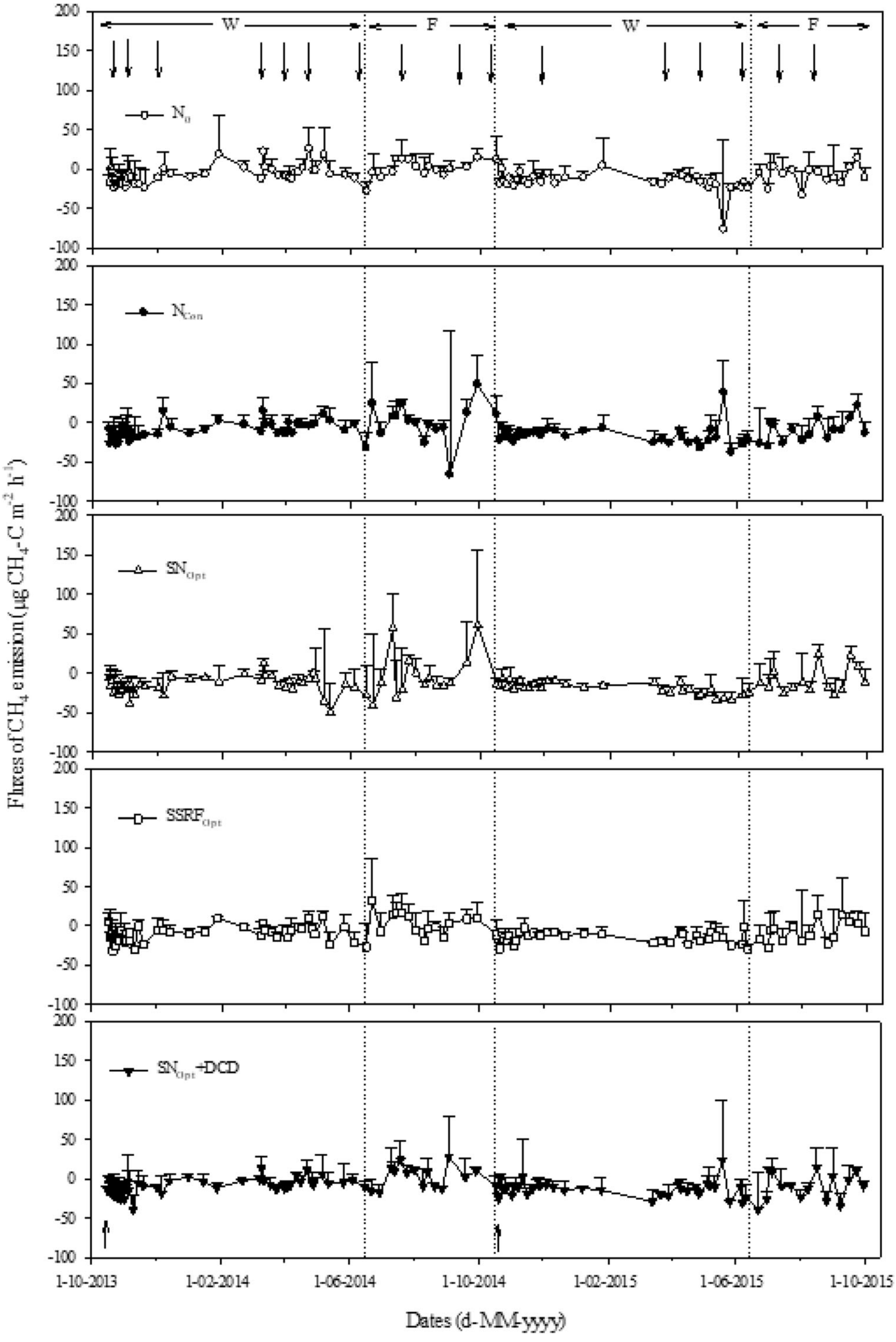

Fig. 4 Mean CH_4 emissions from winter wheat-summer fallow cropping system under rainfed: Wheat cropping season and fallow season are denoted by W and F, respectively; error bars represent standard deviation of the mean ($n = 3$); upward line arrows indicate basal fertilizers application and straw dressing for winter wheat; downward arrows indicate remarkable precipitation (≥8mm) during this study.

SN_{Opt}, SN_{Opt} + DCD and $SSRF_{Opt}$ treatments, respectively. We observed that the N_2O emissions could be effectively minimized by adding 5% of DCD into N fertilization as the SN_{Opt} + DCD treatment under field condition.

It has been understood that the amount of N fertilizer governs the fluxes and cumulative N_2O emissions. Huang et al. (2013a) reported that the 56% reduction of N fertilizer rate to an optimized level noticeably reduced 40% of N_2O emission. In this study, the N fertilizer rates in optimized management practice reduced into 32% lower than conventional management practice. However, cumulative N_2O emissions from optimized practice were considerably increased by over 2-folds

Table 3 Net greenhouse gas and net greenhouse gas intensity in winter wheat summer fallow cropping system under rainfed. The number represents mean ± standard error ($n = 3$); different letters within same column indicate significant differences ($p < 0.05$)

Treatments	N_2O (kg N_2O–N ha^{-1})	CH_4 (kg CH_4–C ha^{-1})	NGHG (kg CO_2-eq ha^{-1})	Grain yield (t ha^{-1})	NGHGI (kg CO_2-eq t^{-1} grain)
For a 3-year period					
N_0	1.09 ± 0.31a	2.19 ± 0.58a	437 ± 163a	12.8 ± 0.20a	102 ± 43a
N_{Con}	2.22 ± 0.47ab	2.63 ± 0.56a	953 ± 229ab	18.1 ± 0.60bc	158 ± 43ab
SN_{Opt}	3.06 ± 0.98b	3.37 ± 0.39a	1322 ± 416b	17.7 ± 0.33b	223 ± 73b
SN_{Opt} + DCD	1.39 ± 0.39a	2.67 ± 0.87a	564 ± 156a	19.5 ± 0.65c	86 ± 23a
$SSRF_{Opt}$	2.66 ± 0.33b	2.47 ± 0.61a	1162 ± 137b	18.3 ± 1.02bc	191 ± 31ab
In 2012–2013					
N_0	0.36 ± 0.18a	0.97 ± 0.53a	138 ± 99a	3.84 ± 0.25a	37 ± 28a
N_{Con}	0.56 ± 0.16a	1.18 ± 0.53a	224 ± 90a	5.43 ± 0.23b	42 ± 17a
SN_{Opt}	0.53 ± 0.08a	1.36 ± 0.16a	202 ± 41a	5.64 ± 0.21bc	36 ± 8a
SN_{Opt} + DCD	0.41 ± 0.06a	1.26 ± 0.19a	149 ± 24a	6.26 ± 0.10d	24 ± 4a
$SSRF_{Opt}$	0.50 ± 0.19a	1.10 ± 0.13a	200 ± 89a	5.95 ± 0.14 cd	33 ± 15a
In 2013–2014					
N_0	0.44 ± 0.04a	0.24 ± 0.23a	197 ± 19a	4.72 ± 0.32a	42 ± 7a
N_{Con}	1.00 ± 0.26abc	0.33 ± 0.25a	456 ± 116ab	6.43 ± 0.86b	73 ± 26a
SN_{Opt}	1.58 ± 0.69bc	0.69 ± 0.56a	717 ± 322ab	6.00 ± 0.12ab	120 ± 55a
SN_{Opt} + DCD	0.64 ± 0.21ab	0.26 ± 0.30a	292 ± 89ab	6.70 ± 0.14b	44 ± 14a
$SSRF_{Opt}$	1.48 ± 0.10b	0.32 ± 0.52a	682 ± 32b	6.12 ± 0.74ab	113 ± 16a
In 2014–2015					
N_0	0.29 ± 0.11ab	0.98 ± 0.35a	102 ± 63a	4.26 ± 0.63a	23 ± 13a
N_{Con}	0.66 ± 0.08bc	1.13 ± 0.15a	273 ± 43ab	6.25 ± 0.32b	44 ± 6ab
SN_{Opt}	0.95 ± 0.17d	1.31 ± 0.03a	403 ± 79c	6.07 ± 0.32b	67 ± 16b
SN_{Opt} + DCD	0.34 ± 0.17a	1.15 ± 0.40a	123 ± 64a	6.59 ± 0.63b	18 ± 8a
$SSRF_{Opt}$	0.67 ± 0.08c	1.05 ± 0.22a	280 ± 42bc	6.21 ± 0.40b	45 ± 8ab

NGHG, net greenhouse gas; *NGHGI*, net greenhouse gas intensity

in 2013–2014 and over 2 and a half folds in 2014–2015 higher than that from conventional practice during cropping season. It indicated that straw incorporation under optimized practice extremely enhanced N_2O emissions instead of decrease in emissions associated with lower N fertilizer rates. The similar results occurred by 58% increase of N_2O emission for summer maize after wheat straw return (Liu et al. 2011), by 27.9% increase of annual mean N_2O emission in straw return and 4 times higher in straw incorporation than in straw removal treatments (Huang et al. 2013a). This phenomenon might be owing to accelerated of microbial nitrification and denitrification processes during straw decomposition together with mineral N and available carbon, as well as suitable temperatures and soil moisture (Vilarrasa-Noguéet al. 2020). Moreover, during cropping seasons, the slow release fertilizer somewhat reduced N_2O emission by 15%, 11%, and 39% in 2012–2013, 2013–2014, and 2014–2015, respectively, compared with SN_{Opt} treatment. The similar result was observed by a 33% decrease in N_2O emission during the winter wheat cropping season when slow release fertilizer was used (Shi et al. 2014).

A 50-mm rewetting after an 18-day drought increased N_2O fluxes by 24-folds in non-conservation reserve program (Gelfand et al. 2015). Therefore, frequency and amount of precipitation, followed by daily temperature, are substantial controlling factors on N_2O emission under rainfed. In this study, rainfall events also regulated the N_2O emissions particularly during cropping season after fertilizer application though the mean values of cumulative N_2O emission within the fallow season which did not change evidently even when higher precipitation was obtained. The amount of rainfall (almost 300 mm) received during the cropping season in 2013–2014 was over 25% more than the first and third cropping seasons, and underwent into 1–2-fold increase in N_2O emissions (Table 1). It could be interpreted that large amount of precipitation with the combination of N fertilizers and straw incorporation under 9–11 °C of soil temperatures can be assumed as a favorable condition for increasing N_2O emissions. Eventually, it can be evaluated through this study that the effectiveness of the treatments for N_2O emissions could be determined during the cropping season. Moreover, the amount of precipitation obtained during cropping season plays as important impact in controlling N_2O emissions under a rainfed monocropping system.

Influences of straw and N fertilizer on grain yield and N use efficiency

In this study, the grain yield varied from 4.26 to 6.70 t ha^{-1}, and it was within the range reported by Zhang et al. (2013) with 4.9 ± 2.0 t ha^{-1} from farmers' practices regarding N fertilizer use in China. At present study, although the optimized practice saved 32% of N fertilizer, the grain yields were not reduced noticeably compared with a conventional practice. Moreover, the SN_{Opt} + DCD treatment produced somewhat higher grain yield with the highest N use efficiency of 33.5% in each winter wheat cropping season. It thus seemed that adding 5% of DCD into N fertilization can inhibit nitrification to prevent losses from N fertilizer as N_2O emissions and lead to have better N use efficiency from applied fertilizers for grain yield increase by 4–5%.

Adaptation of rainfed monocropping system to global warming

Agricultural management approach changes one type of source or sink of global warming potential may also influence other sources or sinks and thus change the NGHG and NGHGI (Shang et al. 2011; Huang et al. 2013b; Xin et al. 2019). In this study, compared with the N_{Con} treatment over a 3-year period, the SN_{Opt} treatment with a 32% decrease in N fertilizer brought about 38% increase in N_2O emission by straw return, about 28% increase in soil CH_4 uptakes, and eventually approximately 39% and 41% increase in NGHG and NGHGI, respectively. Despite the lower N fertilizer input, N_2O emission was higher but not significant due to straw return, leading to increase in NGHG and NGHGI. However, the soil CH_4 uptake influenced by N fertilizers and straw in Northern China Plain is very small (Liu et al. 2012) and the negative global warming potential from CH_4 uptake represented less than 1% for all calculations (Huang et al. 2013a). Again, comparing among the optimized practices with different N management, adding 5% of DCD into urea fertilizer contributed over 55% decrease in N_2O emission, over 10% increase in grain yield, and leading to about 57% and 61% decrease in NGHG and NGHGI, respectively. The use of slow release fertilizer conveyed about 13% reduction in N_2O emission, approximately 3% increase in yield, and then concerned with about 12% and 14% decreased in NGHG and NGHGI, respectively.

The positive annual NGHG and NGHGI for all treatments in the present study was consistent with some previous field and modeling studies. The NGHGI values in our study were 86–223 kg CO_2-eq t^{-1} grain, and definitely lower than the winter wheat-summer maize cropping system, where the values were 252–393-kg CO_2-eq t^{-1} grain (Huang et al. 2013a) because of higher emission factor from irrigated cropland. However, our values were very close to 230-kg CO_2-eq t^{-1} grain from irrigated maize in central Nebraska (Grassini and Cassman 2012) owing to low emission factors. The NGHGI over a 3-year period increased 50% to over 2-folds due to different N fertilizer applications coupling with straw return relative to N_0, although SN_{Opt} + DCD could completely minimize N_2O emission factor. As this present study was carried out during winter wheat-summer fallow monocropping system under rainfed, the NGHGI is absolutely lower than the results of a 3-year field research from rice-wheat annual rotation systems in China which reported that straw management treatments due to different fertilizer applications compared with control were significantly increased by 4–12-folds in the NGHGI (Yang et al. 2015a).

The similar results were reported by Soltani et al. (2013) that 433–1612 kg CO_2-eq ha^{-1} and 173–474 kg CO_2-eq t^{-1} of NGHG and GHGI were obtained from wheat production in Iran. Jin et al. (2014) also suggested that application of manure and synthetic N fertilizers could remarkably decrease NGWP and NGHGI in arid agricultural systems. Therefore, since winter wheat-summer fallow monocropping system under rainfed may reduce considerably NGHG and NGHGI, our results suggest that straw incorporation in optimized management practice enhances the NGHG and GHGI through higher N_2O emission factor dependence upon frequency and amount of precipitation.

The relationship between soil temperature, WFPS, N_2O, and CH_4 emission

Surface soil temperature of 10 cm fluctuates with atmospheric temperature (range − 1.2 to 30.0 °C, mean 14.4 °C). Soil WFPS increased with the occurrence of rainfall and then began to decline due to the soil texture, soil moisture evaporation, and crop absorption. It ranged from 14.21 to 58.29%. N_2O emissions began to increase and then decreased with fertilization, and rainfall had a significant impact on N_2O emissions, especially the SN_{Opt} treatment and the $SSRF_{Opt}$ treatment. In this study, CH_4 emissions decreased to a certain extent in response to rainfall.

Jiang et al. showed that there was no significant relationship between soil temperature, WFPS, and N_2O release (Jiang et al. 2017); the peak of N_2O emissions is after a heavy rain. Studies have found that when the soil WPFS is below 50% and the soil temperature is below 10 °C, the N_2O emissions are relatively low (Hu et al. 2013). Studies have also shown that soil WFPS is higher than 60%, and soil temperature is higher than 10 °C, which is conducive for the release of N_2O (Ma et al. 2010). In the corn-growing season, there was no obvious relationship between soil temperature and N_2O release, probably because the high temperature in the corn season was not a factor limiting the production of N_2O. At the same time, there is no correlation between soil WFPS and N_2O release, because the main factor limiting N_2O emissions is available N, so the peak of N_2O emissions generally occurs after fertilization accompanied by rainfall (Ma et al. 2010). For CH_4 absorption, moderate WFPS (20–60%) is conducive for CH_4 absorption, and studies have shown that temperatures below 10 °C will inhibit CH_4 absorption (Yang et al. 2020a). In dryland, the release of soil N_2O and CH_4 is mainly controlled by soil moisture (Xu and Hosen 2010), rainfall is the main factor of soil moisture, and high temperature can promote the release of CH_4 (Zhang et al. 2015a; Zhang et al. 2015b). A research by Guo et al (Jiang et al. 2017) Showed that there was no significant correlation between soil temperature, WFPS, and CH_4 absorption, but it increased from April to July and declined in winter.

Conclusion

The NGHG in terms of N_2O plus CH_4 fluxes in carbon dioxide equivalent (CO_2-eq) was remarkably influenced by straw incorporation, nitrogen fertilization, and precipitation during a cropping season in rainfed monocropping system. Higher mean values of emission factors were obtained in 2013–2014 than 2012–2013 and 2014–2015 due to higher precipitation. The optimized methods can save about 32% use of N fertilizers without any significant decrease in grain yields relative to conventional farmers' N fertilizer use; however, straw return enhanced N_2O emission orientating to increase NGHG and NGHGI. Across over this study, N_2O emission factor was the lowest at 0.05% derived from N fertilizer by adding 5% of DCD into optimized method under field condition. The use of slow release fertilizer could somewhat decrease in N_2O emission with 0.5% of emission factor compared with optimized method by urea fertilizer with approximately 0.7% emission factor. Since the statistical differences among annual cumulative emissions were observed coinciding with that during the winter wheat growing season, it is a vital and important period for investigation of N_2O emissions from winter wheat-summer fallow monocropping system under rainfed cropland. In addition, the soil in our field acted as a weak sink for atmospheric CH_4 uptake, and further study should be considered to encounter the evaluation of soil carbon sequestration changes due to straw management. It, eventually, can be expected that in order to mitigate N_2O emission, straw return before N fertilizer application as treatment was attractive to avoid residue decomposition processes attributed with N fertilizers.

Funding information This work was funded by the Ministry of Agriculture (grant number: 201103039) and the Key Laboratory of Plant Nutrition and the Agri-environment in Northwest China, Ministry of Agriculture, Shaanxi, China.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Abbreviations C, Carbon; CO_2, Carbon dioxide; DCD, Dicyanodiamide; DOM, Dissolved organic matter; ECD, Electron capture detector; EF, Emission factor; GHG, Greenhouse gas; HI, Harvest index; N, Nitrogen; N_0, No N application; N_2O, Nitrous oxide; NC, Conventional N management; NGHG, Net greenhouse gas emissions; NGHGI, Net greenhouse gas emissions intensity; NGWP, Net global warming potential; SN_{Opt}, Optimized N application with straw; SN_{Opt}, Optimized N management; SN_{Opt} + DCD, Optimized N application with straw and 5% of dicyanodiamide; SRF, Slow release fertilizer; $SSRF_{Opt}$, Optimized N rate of slow release fertilizer with straw; WFPS, Water-filled pore space

References

Akiyama H, Yan X, Yagi K (2010) Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N_2O and NO emissions from agricultural soil: meta-analysis. Global Change Biol 16:1837–1846

Badagliacca G, Benítez E, Amato G, Badalucco L, Giambalvo D, Laudicina V, Ruisi P (2018) Long-term effects of contrasting tillage on soil organic carbon, nitrous oxide and ammonia emissions in a Mediterranean Vertisol under different crop sequences. Sci Total Environ 619-620:18–27

Campanha M, Oliveira A, Marriel I, Neto M, Malaquias J, Landau E, Filho M, Ribeiro F, Carvalho A (2019) Effect of soil tillage and N fertilization on N_2O mitigation in maize in the Brazilian Cerrado. Sci Total Environ 692:1165–1174

Cheng H, Zhu X, Sun R, Niu Y, Yu Q, Shen Y, Li S (2020) Effects of different mulching and fertilization on phosphorus transformation in upland farmland. J Environ Manage 253:109717

Cui F, Yan G, Zhou Z, Zheng X, Deng J (2012) Annual emissions of nitrous oxide and nitric oxide from a wheat–maize cropping system on a silt loam calcareous soil in the North China Plain. Soil Biol Biochem 48:10–19

Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R, Raga G, Dorland MSARV (2007) Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Gao B, Ju X, Su F, Meng Q, Oenema O, Christie P, Chen X, Zhang F (2014) Nitrous oxide and methane emissions from optimized and alternative cereal cropping systems on the North China Plain: a two-year field study. Sci Total Environ 472:112–124

Gelfand I, Cui M, Tang J, Robertson GP (2015) Short-term drought response of N_2O and CO_2 emissions from mesic agricultural soils in the US Midwest. Agric Ecosyst Environ 212:127–133

Geng J, Ma Q, Zhang M, Li C, Liu Z, Lyu X, Zheng W (2015) Synchronized relationships between nitrogen release of controlled release nitrogen fertilizers and nitrogen requirements of cotton. Field Crop Res 184:9–16

Gillette K, Malone R, Kaspar T, Ma L, Parkin T, Jaynes D, Fang Q, Hatfield J, Feyereisen G, Kersebaum K (2018) N loss to drain flow and N_2O emissions from a corn-soybean rotation with winter rye. Sci Total Environ 618:982–997

Grassini P, Cassman KG (2012) Correction for Grassini and Cassman, High-yield maize with large net energy yield and small global warming intensity. P Natl Acad Sci USA 109:4021–4021

Hu X, Su F, Ju X, Gao B, Oenema O, Christie P, Huang B, Jiang R, Zhang F (2013) Greenhouse gas emissions from a wheat—maize double cropping system with different nitrogen fertilization regimes. Environmental Pollution 176:198–207

Huang J, Chen Y, Sui P, Gao W (2013a) Estimation of net greenhouse gas balance using crop- and soil-based approaches: two case studies. Sci Total Environ 456-457:299–306

Huang T, Gao B, Christie P, Ju X (2013b) Net global warming potential and greenhouse gas intensity in a double-cropping cereal rotation as affected by nitrogen and straw management. Biogeosciences 10: 7897–7911

IPCC (2013) Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jiang J, Hu Z, Sun W, Huang Y (2010) Nitrous oxide emissions from Chinese cropland fertilized with a range of slow-release nitrogen compounds. Agric Ecosyst Environ 135:216–225

Jiang J, Wang R, Wang Z, Guo S, Ju X (2017) Nitrous oxide and methane emissions in spring maize field in then, semi-arid regions of Loess Plateau. Clean 45(1):1500271.1–1500271.12

Jin L, Liu X, Liu H, Wang X, Li K, Tian C, Christie P (2014) Greenhouse gas intensity and net annual global warming potential of cotton cropping systems in an extremely arid region. Nutr Cycl Agroecosys 98:15–26

Kahrl F, Li Y, Su Y, Tennigkeit T, Wilkes A, Xu J (2010) Greenhouse gas emissions from nitrogen fertilizer use in China. Environ Sci Policy 13:688–694

Ladha JK, Pathak H, Krupnik T, Six J, van Kessel C (2005) Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. Advances in Agronomy. Academic Press, pp. 85-156.

Liu C, Wang K, Meng S, Zheng X, Zhou Z, Han S, Chen D, Yang Z (2011) Effects of irrigation, fertilization and crop straw management on nitrous oxide and nitric oxide emissions from a wheat–maize rotation field in northern China. Agric Ecosyst Environ 140:226–233

Liu C, Wang K, Zheng X (2012) Responses of N_2O and CH_4 fluxes to fertilizer nitrogen addition rates in an irrigated wheat-maize cropping system in northern China. Biogeosciences 9:839–850

Lu F, Wang X, Han B, Ouyang Z, Duan X, Zheng H (2010) Net mitigation potential of straw return to Chinese cropland: estimation with a full greenhouse gas budget model. Ecol Appl 20:634–647

Ma B, Wu T, Tremblay N, Deen W, Morrison M, McLaughlin NB, Gregorich EG, Stewart G (2010) Nitrous oxide fluxes from corn fields: on-farm assessment of the amount and timing of nitrogen fertilizer. Global Change Biol 16:156–170

Mosier AR, Halvorson AD, Reule CA, Liu X (2006) Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. J Environ Qual 35:1584

Ni K, Ding W, Zaman M, Cai Z, Wang Y, Zhang X, Zhou B (2012) Nitrous oxide emissions from a rainfed-cultivated black soil in Northeast China: effect of fertilization and maize crop. Biol Fert Soils 48:973–979

Qin S, Wang Y, Hu C, Oenema O, Li X, Zhang Y, Dong W (2012) Yield-scaled N_2O emissions in a winter wheat–summer corn double-cropping system. Atmos Environ 55:240–244

Qiu S, Ju X, Lu X, Li L, Ingwersen J, Streck T, Christie P, Zhang F (2012) Improved nitrogen management for an intensive winter wheat/summer maize double-cropping system. Soil Sci Soc Am J 76:286–297

Qiu Q, Wu L, Ouyang Z, Li B, Xu Y, Wu S, Gregorich EG (2015) Effects of plant-derived dissolved organic matter (DOM) on soil CO_2 and N_2O emissions and soil carbon and nitrogen sequestrations. Appl Soil Ecol 96:122–130

Shang Q, Yang X, Gao C, Wu P, Liu J, Xu Y, Shen Q, Zou J, Guo S (2011) Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments. Global Change Biol 17:2196–2210

Shepherd A, Yan X, Nayak D, Newbold J, Moran D, Dhanoa MS, Goulding K, Smith P, Cardenas LM (2015) Disaggregated N_2O emission factors in China based on cropping parameters create a robust approach to the IPCC Tier 2 methodology. Atmos Environ 122:272–281

Shi Y, Wu W, Meng F, Zheng L, Wang D, Ye H, Ding G (2014) Nitrous oxide and methane fluxes during the maize season under optimized management in intensive farming systems of the North China Plain. Pedosphere 24:487–497

Soltani A, Rajabi MH, Zeinali E, Soltani E (2013) Energy inputs and greenhouse gases emissions in wheat production in Gorgan, Iran. Energy 50:54–61

Thers H, Abalos D, Dörsch P, Elsgaard L (2020) Nitrous oxide emissions from oilseed rape cultivation were unaffected by flash pyrolysis biochar of different type, rate and field ageing. Sci Total Environ 724:138140

Trinh TH, Kushaari K, Shuib AS, Ismail L, Azeem B (2015) Modelling the release of nitrogen from controlled release fertiliser: constant and decay release. BiosystEng 130:34–42

Vilarrasa-Nogué M, Teira-Esmatges M, Pascual M, Villar J, Rufat J (2020) Effect of N dose, fertilisation duration and application of a nitrification inhibitor on GHG emissions from a peach orchard. Sci Total Environ 699:134042

Xin Y, Tao F (2019) Optimizing genotype-environment-management interactions to enhance productivity and eco-efficiency for wheat-maize rotation in the North China Plain. Sci Total Environ 654:480–492

Xu H, Hosen Y (2010) Effects of soil water content and rice straw incorporation in the fallow season on CH_4 emissions during fallow and the following rice-cropping seasons. Plant & Soil 335:373–383

Yang B, Xiong Z, Wang J, Xu X, Huang Q, Shen Q (2015a) Mitigating net global warming potential and greenhouse gas intensities by substituting chemical nitrogen fertilizers with organic fertilization strategies in rice–wheat annual rotation systems in China: a 3-year field experiment. Ecol Eng 81:289–297

Yang Y, Zhou C, Li N, Han K, Meng Y, Tian X, Wang L (2015b) Effects of conservation tillage practices on ammonia emissions from Loess Plateau rain-fed winter wheat fields. Atmos Environ 104:59–68

Yang J, Zhang T, Wang Y, Zhang R, Li H (2019a) Intercropped relationship change the developmental pattern of apple and white clover. Bioengineered 10(1):218–228. https://doi.org/10.1080/21655979.2019.1621137

Yang J, Zhang T, Zhang R, Huang Q, Li H (2019b) Long-term cover cropping seasonally affects soil microbial carbon metabolism in an apple orchard. Bioengineered 10(1):207–217. https://doi.org/10.1080/21655979.2019.1622991

Yang W, Feng G, Mile D, Gao L, Jia Y, Li C, Qu Z (2020a) Impact of biochar on greenhouse gas emissions and soil carbon sequestration in corn grown under drip irrigation with mulching. Sci Total Environ https://doi.org/10.1016/ j.scitotenv.2020.138752.

Yang J, Duan Y, Yang X, Awasthi MK, Li H, Zhang H (2020b) Modeling CO_2 exchange and meteorological factors of an apple orchard using partial least square regression. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-07123-5

Yang J, Duan Y, Wang L, Kang D, Awasthi MK, Li H, Zhang H (2020c) Seasonal variation of net ecosystem CO_2 exchange and its influencing factors in an apple orchard in the Loess Plateau. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-08526-5

Zhang A, Cui L, Pan G, Li L, Hussain Q, Zhang X, Zheng J, Crowley D (2010) Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agric Ecosyst Environ 139:469–475

Zhang W, Dou Z, He P, Ju X, Powlson D, Chadwick D, Norse D, Lu Y, Zhang Y, Wu L, Chen X, Cassman KG, Zhang F (2013) New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. P Natl Acad Sci USA 110:8375–8380

Zhang L, Zheng J, Chen L, Shen M, Zhang X, Zhang M, Bian X, Zhang J, Zhang W (2015a) Integrative effects of soil tillage and straw management on crop yields and greenhouse gas emissions in a rice–wheat cropping system. European Journal of Agronomy 63:47–54

Zhang ZS, Guo LJ, Liu TQ, Li CF, Cao CG (2015b) Effects of tillage practices and straw returning methods on greenhouse gas emissions and net ecosystem economic budget in rice–wheat cropping systems in central China. Atmospheric Environment 122

Zhang Y, Wang J, Dai S, Sun Y, Chen J, Cai Z, Zhang J, Müller C (2019) Temperature effects on N_2O production pathways in temperate forest soils. Sci Total Environ 691:1127–1136

Zheng X, Mei B, Wang Y, Xie B, Wang Y, Dong H, Xu H, Chen G, Cai Z, Yue J, Gu J, Su F, Zou J, Zhu J (2008) Quantification of N_2O fluxes from soil–plant systems may be biased by the applied gas chromatograph methodology. Plant Soil 311:211–234