Agricultural Water Management 163 (2016) 403–407

Contents lists available at ScienceDirect

Agricultural Water Management

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

Short communication

Mitigated CH_4 and N_2O emissions and improved irrigation water use efficiency in winter wheat field with surface drip irrigation in the North China Plain

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A R T I C L E   I N F O

Article history:
Received 3 March 2015
Received in revised form
20 September 2015
Accepted 14 October 2015
Available online 28 October 2015

Keywords:
Three irrigation methods
Greenhouse gas
Yield
Soil temperature
Soil moisture

A B S T R A C T

Effects of different irrigation methods on greenhouse gas (GHG) emissions in winter wheat field are poorly understood. In this study, emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were investigated in winter wheat field irrigated with surface drip irrigation (SDI), sprinkler irrigation (SI) and flood irrigation (CK) from 1 April to 31 May of 2014 in the North China Plain. The results showed that SDI increased CH_4 uptake by 22.9%, reduced N_2O emission by 14.6%, improved irrigation water use efficiency (IWUE) by 44.2%, and could keep yield steady. IWUE and yield of winter wheat in SI was greater than that in CK by 28.2% and 8.5%, respectively. These combined results indicated that SDI may not only guarantee yield stability, but also mitigate GHG (CH_4 and N_2O) emissions and improve IWUE. Therefore, more attention should be paid to apply SDI in winter wheat field in the North China Plain.

1. Introduction

Drastic global warming caused by rapid increase of greenhouse gas (GHG) emissions have become a common concern of the international community (IPCC et al., 2007). Agriculture is reported to release large amounts of GHG such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) to the atmosphere (Johnson et al., 2007; Robertson, 2000; Smith et al., 2008). The rapidly growing population influencing food consumption are placing unprecedented demands for extensive agriculture (Foley et al., 2011). Irrigated agriculture plays a vital role in meeting the growing global food demand under the influence of climate change (Piao et al., 2010; Scheer et al., 2012). On the other hand, irrigation itself might affect climate change by altering the capacity of soils to act as sink or source of GHG (Lal, 2004). Hence, to understand the relationship between irrigation practices and GHG emissions is important.

Wheat (*Triticum aestivum* L.) as the second primary crop is particularly important for food sufficiency in China. North China Plain (NCP) is the most important winter wheat production area in China. The natural rainfall is not enough for winter wheat water requirement, thus irrigation is necessary for winter wheat production in this area (Shi et al., 2013). Although flood irrigation is still the most common irrigation practices in the NCP, the area with water-saving irrigation techniques (e.g. surface drip irrigation and sprinkler irrigation) have been substantially increased with government subsidy in recent years (Gao et al., 2014). However, recent researches on GHG emissions from agricultural irrigation mostly was concentrated on making comparisons between irrigated and non-irrigated fields, lacking comparisons between different irrigation methods (Kennedy et al., 2013; Trost et al., 2013). Therefore, information on GHG emissions from winter wheat agro-ecosystem in response to different irrigation methods in the NCP are necessary and planned to be studied. The objectives of this study were: (i) to estimate the emissions of CO_2, CH_4 and N_2O from winter wheat field with different irrigation methods; (ii) to correlate the GHG emissions with soil temperature and soil moisture under different irrigation methods; (iii) to determine irrigation water use efficiency (IWUE) under different irrigation methods in the NCP.

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http://dx.doi.org/10.1016/j.agwat.2015.10.012
0378-3774/

Table 1
Emission of greenhouse gas (CO_2, CH_4 and N_2O), yield, and irrigation water use efficiency (IWUE) of the winter wheat field with three irrigation methods. Values are means ± standard errors ($n = 3$).

Treatments	CO_2 flux ($mg\,m^{-2}\,h^{-1}$)	CH_4 flux ($\mu g\,m^{-2}\,h^{-1}$)	N_2O flux ($\mu g\,m^{-2}\,h^{-1}$)	Yield ($kg\,hm^{-2}$)	IWUE[a] ($kg\,m^{-3}$)
CK	657.69 ± 12.88ab	−40.19 ± 2.61b	48.33 ± 2.25a	7650.77 ± 105.53b	3.19 ± 0.044c
SDI	644.02 ± 9.08b	−49.41 ± 1.46a	41.29 ± 2.00b	7354.63 ± 111.44b	4.60 ± 0.070a
SI	668.44 ± 11.07a	−37.63 ± 2.30b	49.30 ± 2.04a	8304.37 ± 78.22a	4.09 ± 0.033b

[a] Flood irrigation was applied according to local farmer's traditional irrigation frequency and irrigation water amount. Irrigation date: 24 March and 7 May with 800 $m^3\,ha^{-1}$ each time. The water-saving irrigation technologies (drip irrigation and sprinkler irrigation) have different irrigation frequency and water amount. Drip irrigation was applied at 24 March, 16 April and 7 May with 266.67 $m^3\,ha^{-1}$ each time. Sprinkler irrigation was applied at the same date of drip irrigation, with 400 $m^3\,ha^{-1}$ each time. Pre-seeding irrigation 800 $m^3\,ha^{-1}$ was applied by surface flooding for all treatments. IWUE were calculated as yield divided by irrigation amount, CK: flood irrigation, SDI: surface drip irrigation, SI: sprinkler irrigation.

2. Materials and methods

2.1. Site and experimental design

The field experiments were carried out in a maize/wheat rotational field on Xinxiang comprehensive experimental station of Chinese Academy of Agricultural Sciences (35° 08′N, 113° 45′E, elevation 76 m), located at Xinxiang City of Henan province, south part of the North China Plain. Average rainfall and temperature at the experimental site is 165 mm and 9.9 °C during winter wheat growing season, respectively. The experimental soil is sandy loam with mean bulk density of 1.5 $g\,cm^{-3}$ and mean field capacity of 20.5% (mass basis) in 0–100 cm soil profile. Average available N, P, and K contents of of top layer soil (0–20 cm) were 59.28, 11.97 and 123.54 $mg\,kg^{-1}$, respectively. Soil organic matter content was 1.64 $g\,kg^{-1}$ and soil pH was 8.6.

A popular winter wheat variety Zhengmai 366 was sown at rate of 180 $kg\,ha^{-1}$ on 20 October, 2013. Flood irrigation (CK), surface drip irrigation (SDI) and sprinkler irrigation (SI) were applied as irrigation method treatments from re-green stage of winter wheat, with three replicates, respectively. Each plot was 6 m wide and 10 m long, included 40 crop rows spaced 25 cm and planted at north-south direction. The yield of winter wheat was measured using 1 m^2 quadrate. In all treatments, NPK (Nitrogen-Phosphorus-Potassium) compound fertilizer at a rate of 600 $kg\,ha^{-1}$ were applied before sowing, while granular urea at a rate of 150 $kg\,ha^{-1}$ were manually broadcasted at the re-green stage before an irrigation. Samples were collected from 1 April to 28 May in 2014.

2.2. Sampling and analyzing

Emissions of CO_2, CH_4, and N_2O in all treatments were measured at an interval of two days using an opaque, static and stainless steel chamber by gas chromatography technique. All the chambers were equipped with a fan inside to ensure complete gas mixing. Four gas samples were collected from each chamber using 100 ml nylon syringe at 10-min intervals between 09:00 and 12:00 in the morning on every sampling day (Mosier et al., 1991). Agilent 7890A gas chromatograph (Agilent Technologies, Wilmington, DE, USA) was used to analyze GHG concentrations within 72 h after gas sampled. The gas emission were calculated according to the slope of the linear regression between concentration and time using the equation described by Song et al. (2003).

$$J = \frac{dc}{dt}\frac{M}{V_0}\frac{P}{P_0}\frac{T_0}{T}H$$

Where J is emission flux ($mg\,m^{-2}\,h^{-1}$), dc/dt is the slope of the linear regression of gas concentration at time approaching zero, M is the mole mass of the measured gas ($g\,mol^{-1}$), P is the atmospheric pressure (Pa), T is the absolute temperature (K); V_0, P_0, T_0 are volume (ml) and absolute temperature (K) and pressure (Pa) at standard condition, H is chamber height above water surface (cm).

2.3. Soil temperature and moisture

Soil temperature and moisture at 10 cm depth below soil surface in each treatment was measured with temperature probes (Testo, 0560.1110, Freiburg, Germany) and Field Scout TDR-300 portable moisture meter (Spectrum Technologies, Inc., Plainfield, IL, USA) at the same day for gas sampling.

2.4. Statistical analysis

The differences of CO_2, CH_4 and N_2O emissions from different irrigation method treatments were analyzed using a one-way ANOVA analysis and post hoc Fisher's LSD tests. To explore the effects of sample date and the changes of treatment, the repeated-measures ANOVA was carried out with sample date as the repeated factor. Simple correlation analyses were used to identify the relationship between environmental variables and GHG emissions. Results were judged to be significant at $P < 0.05$. Statistical analyses were performed using the SPSS 16.0 (SPSS Inc., Chicago, Ill, USA).

3. Results

3.1. Environmental variables

Daily rainfall and daily mean air temperature from 1 April to 31 May, 2014 are illustrated in Fig. 1. Total rainfall amount of 103.6 mm was distributed in 17 rainy days. Daily mean air temperature increased gradually during the experimental period, with an average of 15.2 °C. The minimum daily mean air temperature of 5.8 °C appeared on 6 April and the maximum daily mean air temperature of 24.6 °C was measured on 28 of May.

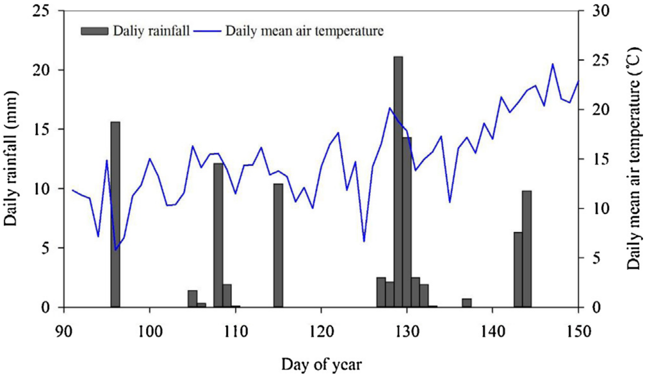

Fig. 1. Daily rainfall and daily mean air temperature during the experimental period from 1 April to 31 May, 2014.