Science of the Total Environment 646 (2019) 290–299

Contents lists available at ScienceDirect

Science of the Total Environment

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

Irrigation reduces the negative effect of global warming on winter wheat yield and greenhouse gas intensity

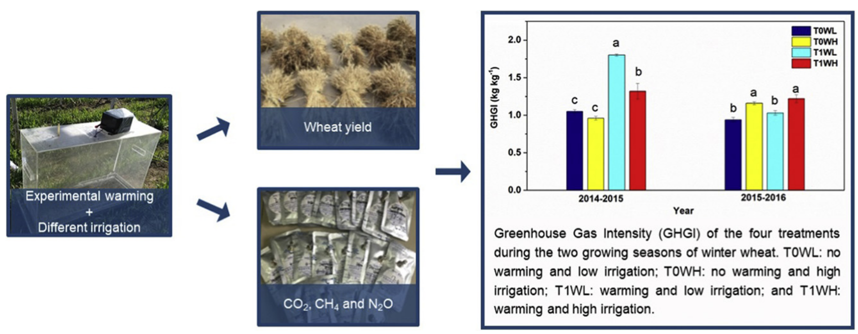
Jiazhen Li [a,b], Wenxu Dong [a], Oene Oenema [c], Tuo Chen [a,b], Chunsheng Hu [a,*], Haijing Yuan [d], Liying Zhao [a,b]

[a] *Key Laboratory of Agricultural Water Resources, Hebei Laboratory of Agricultural Water-Saving, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, China*
[b] *University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, China*
[c] *Wageningen Environmental Research, Wageningen University and Research, 6700AA Wageningen, the Netherlands*
[d] *College of Resources and Environment, Fujian Agriculture and Forestry University, Fuzhou, 350002, China*

HIGHLIGHTS

- Warming decreased wheat yield in the relatively dry year.
- Supplemental irrigation nullified the warming effect on wheat yield in the dry year.
- Warming increased soil CO_2 emissions and CH_4 uptake, and decrease N_2O emissions.
- Supplemental irrigation increased N_2O emissions but not CO_2 and CH_4 emissions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 April 2018
Received in revised form 20 July 2018
Accepted 20 July 2018
Available online 21 July 2018

Editor: Elena Paoletti

Keywords:
Warming
Irrigation
Greenhouse gases
Wheat yield
Global warming potential
Greenhouse gas intensity

ABSTRACT

Global warming may exacerbate drought, decrease crop yield and affect greenhouse gas (GHG) emissions in semi-arid regions. However, the interactive effects of increases in temperature and water availability on winter wheat yield and GHG emissions in semi-arid climates are not well-understood. Here, we report on a two-year field experiment that examined the effects of a mean soil temperature increase of ~2 °C (at 5 cm depth) with and without additional irrigation on wheat yield and GHG emissions. Infrared heaters were placed above the crop canopy at a height of 1.8 m to simulate warming. Fluxes of CH_4, CO_2 and N_2O were measured using closed static chamber technique once per week during the wheat growing seasons. Warming decreased wheat yield by 28% in the relatively dry year of 2015, while supplemental irrigation nullified the warming effect completely. Warming did not alter the wheat yield significantly in the relatively wet year of 2016, but supplemental irrigation with no warming decreased the wheat yield by 25%. Warming increased CO_2 emissions by 28% and CH_4 uptake by 24% and tended to decrease N_2O emissions. Supplemental irrigation increased N_2O emissions but had little effect on CO_2 emissions and CH_4 uptake. Evidently, warming and supplemental irrigation had interactive effects on wheat yield, GHG emissions and GHG emissions intensity. Precision irrigation appears to be a means of simultaneously increasing wheat yield and reducing GHG emissions under warming conditions in semi-arid areas.

1. Introduction

According to the most recent assessment report of the IPCC, the global mean surface temperature between 2046 and 2065 will be 0.4

* Corresponding author.
E-mail address: cshu@sjziam.ac.cn (C. Hu).

https://doi.org/10.1016/j.scitotenv.2018.07.296
0048-9697/© 2018 Published by Elsevier B.V.

to 2.6 °C higher than it was from 1986 to 2005. For the period of 2081–2100, the global mean surface temperature will increase by 0.3–4.8 °C (Stocker et al., 2013). This global warming will affect crop yields (Challinor et al., 2014; Liu et al., 2013; Zhao et al., 2016a), nitrogen (N) and carbon (C) cycles in the plant–soil system (Luo et al., 2001; Melillo et al., 2002; Patil et al., 2010), and the emissions of the greenhouse gases (GHGs), including nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) (Bijoor et al., 2008; Cosentino et al., 2012; Oberbauer et al., 2007).

Wheat is a main crop in the world in terms of acreage and total production, and a major source of carbohydrates, protein and other nutrients for millions of people (Asseng et al., 2011). It is relatively well-adapted to a wide range of climatic conditions. Yet, global warming is expected to have negative impacts on the growth of winter wheat in semi-arid regions. Mitchell et al. (1993) found that an increased temperature shortened the duration of wheat growth stages, thus leading to decreased yields. Asseng et al. (2015) concluded that the decrease of wheat yield with an increase of temperature is mainly due to the shortening of the growth period and the reduction of the number of spikes. Asseng et al. (2011) examined the impacts of possible changes in temperature and evapotranspiration on wheat yield through simulation modelling. Their results suggest that the combined effects of changes in temperature and evapotranspiration on wheat yield are larger than the temperature effect alone. Evidently, such possible effects require experimental verification. At the same time, it is important to test possible adaptation strategies to global warming, because future global food insecurity is likely to be threatened by global warming (Wheeler and Von Braun, 2013).

Warming may also change net GHG emissions from agroecosystems (Kirschbaum, 2000; Rustad et al., 2001; Crowther et al., 2016). Agriculture contributes significantly to total global emissions, and total emissions are continuously increasing. Total GHG emissions from agriculture were 5335 Mt CO_2 equivalents yr^{-1} in 2011, the highest level in history, and were almost 9% higher than the decadal average of 2001–2010 (Tubiello et al., 2014). The increase in GHG emissions from agriculture is largely associated with the increases in crop and livestock production and the associated land use changes, most notably deforestation. GHG emissions from agriculture are sensitive to changes in temperature and rainfall (e.g., Kirschbaum, 2000; Crowther et al., 2016). Warming generally increases CO_2 emissions (Rustad et al., 2001; Graham et al., 2014), but changes in crop yield may have a counter effect. Liu et al. (2015) found that warming decreased CH_4 uptake by the soil, likely because of soil drying. Warming has also been observed to decrease N_2O emissions due to a lower soil water content (Cosentino et al., 2012; Liu et al., 2016). Evidently, the interactions between changes in temperature and soil moisture in crop yields and GHG emissions are complex, and not well-understood.

The main purpose of the current work was to examine the interactive effects of warming and irrigation on winter wheat yield and CO_2, CH_4, and N_2O emissions. We hypothesized that, under semi-arid conditions, warming in combination with sufficient irrigation would increase wheat yield and net GHG emissions, while warming with little irrigation would decrease wheat yield and net GHG emissions. A factorial field experiment was performed in the semi-arid North China Plain (NCP) to test the aforementioned hypothesis. The North China Plain is major wheat, maize and vegetable growing area, supplying food to hundreds of million people.

2. Materials and methods

2.1. Experimental site

The warming experiment was conducted at the Luancheng Agro-Ecosystem Experimental Station in the North China Plain in Hebei (37°53′ N, 114°41′E; elevation 50 m above sea level), during two winter wheat growing seasons between October 2014 and the end of May 2016. The North China Plain is major wheat, maize and vegetable growing area, supplying food to hundreds of million people. The experimental station is situated in a semi-arid monsoon climate region and has relatively high wheat yields under irrigation. The soil at the experimental site is sandy loam. The soil organic matter content is 15 g kg^{-1}, total nitrogen is 1.1 g kg^{-1}, available phosphorus (P-Olsen) is 15 mg kg^{-1}, and exchangeable potassium is 95 mg kg^{-1} in the top 0–20 cm soil layer. Additional information on soil characteristics can be found in Liu et al. (2016). The annual average temperature between 2014 and 2016 was 12.3 °C, and the annual average precipitation was 481 mm. Information on the mean daily temperature, precipitation and conventional irrigation regime at the Luancheng station during this period is provided in Fig. 1.

The main crops in the studied region include winter wheat (*Triticum aestivu* L.) and maize (*Zea mays* L.) often grown in sequence as a double cropping system. We focused on winter wheat only, and no second crop was cultivated after winter wheat.

2.2. Experimental design

A randomized two-factorial experimental design was used with two temperature treatments (T0: ambient temperature; T1: increased temperature (~2 °C at a soil depth of 5 cm) and two flood irrigation treatments (WL: low irrigation, equivalent to 60 mm precipitation per event; WH: high irrigation, equivalent to 90 mm precipitation per event). Treatment WL constitutes the conventional irrigation regime. There were three (in 2014/2015) or four (in 2015/2016) irrigation events per year for both WL and WH, and four treatments in total: T0WL, T0WH, T1WL and T1WH. Each treatment had three replications. Each plot was 4 × 2 m^2.

A common local cultivar in Hebei Province, namely "Shixin 828," was manually sown in October. At sowing, fertilizer N (urea) was applied as 120 kg N ha^{-1} and P fertilizer was applied as 65 kg P ha^{-1}. In addition, another 120 kg N ha^{-1} was applied as topdressing in March. The wheat straw was removed after harvesting according to the local practice. There are three times irrigation (December, March, and May) when wheat reached wintering, jointing, and heading stages. In 2016, exceptional irrigation was added in middle of April because of the low precipitation in spring (Fig. 1).

Eighteen radiant infrared heaters covering areas of 200 × 20 cm were installed with a power rating of 1000 watt m^{-2} (Liu et al., 2015). These heaters were set at the height of 1.8 m in the heated plots (T1) throughout the entire growth season of wheat from seeding to

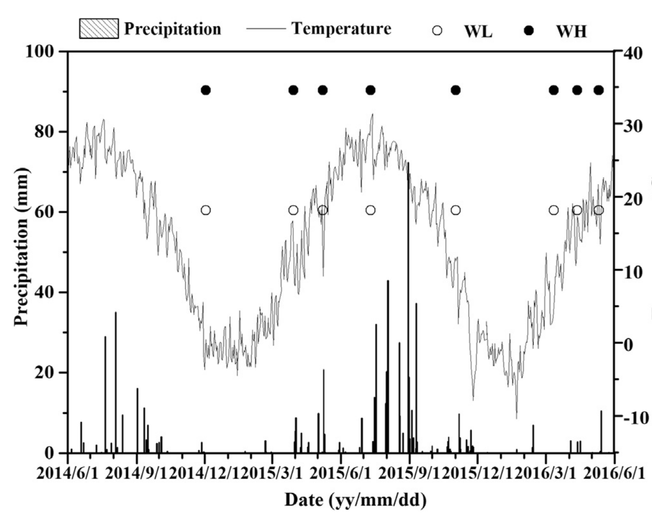


Fig. 1. Precipitation, daily mean temperature and irrigation events at the experimental field from 2014 to 2016. WL means low irrigation (60 mm per event), and WH means high irrigation (90 mm per event).