JOURNAL OF ENVIRONMENTAL SCIENCES 34 (2015) 1–9

Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences

JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Ozone concentrations, flux and potential effect on yield during wheat growth in the Northwest-Shandong Plain of China

Zhilin Zhu[1,*], *Xiaomin Sun*[1,*], *Fenghua Zhao*[1], *Franz X. Meixner*[2]

1. *Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.* E-mail: zhuzl@igsnrr.ac.cn

2. *Biogeochemistry Department, Max-Planck-Institute for Chemistry, 55128 Mainz, Germany*

ARTICLE INFO

Article history:
Received 10 October 2014
Revised 8 December 2014
Accepted 15 December 2014
Available online 5 May 2015

Keywords:
Ozone concentration
Ozone flux
Deposition velocity
Eddy covariance
Yield loss estimation
Cropland ecosystem

ABSTRACT

Ozone (O_3) concentration and flux (F_o) were measured using the eddy covariance technique over a wheat field in the Northwest-Shandong Plain of China. The O_3-induced wheat yield loss was estimated by utilizing O_3 exposure-response models. The results showed that: (1) During the growing season (7 March to 7 June, 2012), the minimum (16.1 ppbV) and maximum (53.3 ppbV) mean O_3 concentrations occurred at approximately 6:30 and 16:00, respectively. The mean and maximum of all measured O_3 concentrations were 31.3 and 128.4 ppbV, respectively. The variation of O_3 concentration was mainly affected by solar radiation and temperature. (2) The mean diurnal variation of deposition velocity (V_d) can be divided into four phases, and the maximum occurred at noon (12:00). Averaged V_d during daytime (6:00–18:00) and nighttime (18:00–6:00) were 0.42 and 0.14 cm/sec, respectively. The maximum of measured V_d was about 1.5 cm/sec. The magnitude of V_d was influenced by the wheat growing stage, and its variation was significantly correlated with both global radiation and friction velocity. (3) The maximum mean F_o appeared at 14:00, and the maximum measured F_o was −33.5 nmol/(m^2·sec). Averaged F_o during daytime and nighttime were −6.9 and −1.5 nmol/(m^2·sec), respectively. (4) Using O_3 exposure-response functions obtained from the USA, Europe, and China, the O_3-induced wheat yield reduction in the district was estimated as 12.9% on average (5.5%–23.3%). Large uncertainties were related to the statistical methods and environmental conditions involved in deriving the exposure-response functions.

Introduction

Ground-level ozone (O_3) is a secondary pollutant with adverse effects on plant growth, photosynthesis, and crop yields (Heck et al., 1982; Cape, 2008; Feng et al., 2008). The O_3 concentration is determined by its photochemical reactions with NO_x ($NO + NO_2$) and VOCs (Volatile Organic Compounds) as well as horizontal and vertical large-scale transport (Crutzen et al., 1999; Cape, 2008). According to long-term observations across the globe, ground O_3 concentration levels have been increasing in the past several decades (Monks, 2000; Vingarzan, 2004). In China, fast-paced industrialization and ever-increasing numbers of fossil-fueled vehicles have produced significant amounts of VOCs and NO_x, which have led to rapidly increasing atmospheric O_3 concentrations (Wang et al., 2009; Li et al., 2014). The elevated O_3 concentration is threatening crop production in China (Aunan et al., 2000; Wang and Mauzerall, 2004; Wang et al., 2007; Zhu et al., 2011).

Two kinds of metrics, O_3 concentration or exposure-based indices, and flux-based indices, were applied to assess the effect

* *Corresponding authors.* E-mail: sunxm@igsnrr.ac.cn (Xiaomin Sun).

http://dx.doi.org/10.1016/j.jes.2014.12.022

of O_3 on plants and ecosystems (Musselman et al., 2006; Pleijel et al., 2007). The former are metrics related to the atmospheric environment that do not consider the status of vegetation and ecosystems, *e.g.*, stomatal conductance, leaf area index, and growing stages. Plant response to O_3 is closely related to the amount absorbed into leaf tissue, so stomatal O_3 uptake is considered a better metric than ambient O_3 concentration to evaluate the O_3-induced yield loss (Pleijel et al., 2004; Paoletti and Manning, 2007). One of the well-established methods to quantify stomatal O_3 uptake is to measure total O_3 flux (F_o) over an ecosystem and then partition F_o into stomatal (F_{st}) and non-stomatal uptake (F_{ns}) by using resistance models (Gerosa et al., 2003; Lamaud et al., 2009).

Currently, the eddy covariance method is considered the best micrometeorological technique for measuring ecosystem fluxes (Grünhage et al., 2000; Baldocchi, 2003). Due to a lack of robust and high performance fast-response gas analyzers that can be deployed in the field on a long-term basis, several short-term O_3 flux measurements have been carried out in the past few decades (Gerosa et al., 2003; Lamaud et al., 2009). In China, studies of the effects of O_3 on plants have mainly centered on OTC (open top chamber) or FACE (free-air concentration enhancement) experiments (Feng et al., 2003; Zhu et al., 2011; Feng et al., 2012). To our knowledge, there have been few investigations on O_3 flux at the ecosystem level in China.

One purpose of studying O_3 concentration and flux over a cropland ecosystem is to assess the yield loss caused by O_3. To quantify these losses, some O_3 exposure/flux-response models have been generated by using OTC or FACE experiments (Heck et al., 1982; Mills et al., 2007; Feng et al., 2012; Wang et al., 2012). Although flux-based indices have advantages over exposure-based indices owing to their linkage to stomatal uptake of plants, there are some practical limitations that hinder their use in current research. Such limitations include the lack of continuous stomatal O_3 flux estimations and suitable flux-based assessment models. In contrast, yield loss estimations utilizing O_3 exposure-response functions are relatively easy (Wang and Mauzerall, 2004; Van Dingenen et al., 2009; Avnery et al., 2011).

The Northwest-Shandong Plain of China is an important grain production base, and wheat is a high O_3-sensitivity crop (Mills et al., 2007). To investigate the current O_3 status over the cropland ecosystem and to assess the effect of O_3 on crop yield, O_3 concentration and flux over a wheat field were measured by using the eddy covariance technique. The objectives of the study were to investigate: (1) the relationship of O_3 concentration with environmental factors and the diurnal and seasonal variations of O_3 concentration; (2) the relationships of O_3 deposition velocity and flux with environmental factors or other fluxes as well as their diurnal and phenological variations; and (3) the O_3-induced wheat yield loss at current O_3 levels by using exposure-response functions.

1. Materials and methods

1.1. Site description

The observations were conducted over a winter wheat (*Triticum aestivum* L.) field at the Yucheng Comprehensive Experiment Station of the Chinese Academy of Sciences (36°50′ N, 116°34′ E, 28 m asl.; Shandong Province, China). The site is located in the Yellow River alluvial plain of the North China Plain, characterized by loamy soil texture as well as a semiarid and warm temperate climate. The mean annual temperature and precipitation are 13.4°C and 567 mm, respectively. The main growing season of winter wheat is from March to early June. The experimental site is fairly flat, and fetch requirements for eddy covariance measurements are well satisfied within 200 m of the instrument locations. The canopy height of the winter wheat increased from 0.05 m to 0.75 m during the field experiment from 7 March to 7 June, 2012.

1.2. Data collection

The absolute concentration of ambient O_3 was measured with a slow-response portable UV-absorption based O_3 analyzer (Model 205, 2B Technologies Inc. CO., Boulder, Colorado, USA; hereafter referred to as M205). It has a detection limit of 1 ppbV and its output rate was set to 2 sec. Ozone flux was measured with the eddy covariance method in combination with observations from the Chinese Terrestrial Ecosystem Flux Observational Research Network (ChinaFLUX) (Yu et al., 2006). The instrumentation includes a 3D sonic anemometer (CSAT3, Campbell Scientific Instruments, Logan, Utah, USA) and an open-path CO_2/H_2O gas analyzer (LI-7500, LI-COR Biosciences, Lincoln, Nebraska, USA). The O_3 fluctuation was measured with a fast-response O_3 analyzer (Enviscope GmbH, Frankfurt am Main, Germany), hereafter referred to as ENVI. The measurement principle is based on the chemiluminescence reaction of O_3 with an ozone-sensitive dye layer on an aluminum plate placed in the cell. Although its response time can reach 0.1 sec, the sensitivity is affected by the consumption of dye and environmental conditions, particularly the air humidity (Güsten et al., 1996; Muller et al., 2010). More information about the analyzer can be found in Zahn et al. (2012). Air was drawn into the two analyzers through two PTFE (Teflon) tubes that were 3 m long with a 4 mm interior diameter. The mean delay time (2.8 sec) was calculated by the maximum covariance method. The ENVI's output signal (in mV) was calibrated by the ambient O_3 concentration. Micrometeorological and radiation variables were also measured, including air temperature and relative humidity (HMP45C, Vaisala Co., Finland), wind speed (A100R, Vector Instruments, UK), net radiation (CNR1, Kipp & Zonen, the Netherlands), and photosynthetically active radiation (LI-190SB, LI-COR Biosciences, USA).

All sensors were installed at 2.2 m height. The sampling frequency was 10 Hz. Two gas intake tubes were mounted next to the sonic anemometer center with 0.2 m horizontal separation. Due to the continuous consumption of organic dye, ENVI's sensitivity slowly decreased with time. To maintain high sensitivity, we replaced the organic dye disc every 3 to 4 days. 10 Hz raw data from the eddy covariance (EC) system and 30-min mean data were recorded by a data-logger (CR5000, Campbell Scientific Instrument, Logan, Utah, USA).

1.3. Eddy covariance O_3 flux calculation and data post-processing

The eddy covariance method is based on the statistics involved in vertical turbulent exchange of scalars. Because the ENVI's