Agricultural and Forest Meteorology 256–257 (2018) 1–9

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Assessment of the effect of plastic mulching on soil respiration in the arid agricultural region of China under future climate scenarios

Yongxiang Yu[a,b], Hui Tao[b], Huaiying Yao[a,c,d], Chengyi Zhao[b,*]

[a] Research Center for Environmental Ecology and Engineering, School of Environmental Ecology and Biological Engineering, Wuhan Institute of Technology, 206 Guanggu 1st Road, Wuhan 430205, China
[b] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, 818 South Beijing Road, Urumqi 830011, China
[c] Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China
[d] Key Laboratory of Urban Environmental Processes and Pollution Control, Ningbo Urban Environment Observation and Research Station, Chinese Academy of Sciences, 88 Zhongke Road, Ningbo 315800, China

ARTICLE INFO

Keywords:
DNDC
Soil CO_2
Emission
Plastic film
Oasis cotton field

ABSTRACT

The application of plastic film to agricultural fields has been widely used in the arid and semi-arid regions of China to improve crop productivity and soil organic carbon storage. However, the impact of this practice on soil respiration under future climate scenarios remains poorly understood. Process-based model is a useful tool for simulating the effect of this practice on soil biochemical processes and for predicting future changes in soil respiration under different climate scenarios. In this study, the denitrification-decomposition (DNDC) model was evaluated against measured soil respiration. The DNDC model was used to simulate the temporal variation of soil respiration, and the application of plastic film increased the cumulative carbon dioxide (CO_2) emissions compared with that of the fields without plastic film. Sensitivity tests indicated that plastic mulching decreased the sensitivity of DNDC-simulated soil respiration and plant biomass to changes in the temperature, precipitation and CO_2 concentration. Across different climate scenarios, the DNDC model predicted that both soil respiration and plant biomass in the mulched treatment slightly changed from −0.2% to 2.1% and from −0.7% to 1.2%, respectively; and in the non-mulched treatment, soil respiration and biomass changed from −4.7% to 10.9% and from −8.7% to 7.8%, respectively. In the arid agricultural region of China, if the pollution of residual mulch film in the fields can be effectively controlled, the application of plastic film is an efficient method for increasing crop productivity and would likely mitigate changes in soil respiration under future climate scenarios.

1. Introduction

Soil respiration, the sum of autotrophic (root) and heterotrophic respiration, is recognized as the source of one of the largest carbon (C) fluxes from terrestrial ecosystems to the atmosphere (Hanson et al., 2000). On the global scale, it is estimated that soils have released 91 Pg C $year^{-1}$ to the atmosphere through root (51 Pg C $year^{-1}$) and heterotrophic (40 Pg C $year^{-1}$) respiration over the past 50 years (Hashimoto et al., 2015). Agricultural soils are important sources of carbon dioxide (CO_2) emissions, accounting for approximately 10% of the total soil respiration (Raich et al., 2002). In general, the soil respiration rate from croplands is lower than that from grasslands and forests as the soil organic carbon (SOC) storage is lower in croplands than in grasslands and forests with similar temperature and moisture conditions (Chen et al., 2010). However, in the arid region of China, soil biological activities in natural ecosystems are largely inhibited by low water and nutrition availability (Su et al., 2016). In this region, soil respiration from agriculture ecosystems is greater (2–5 times) than that from natural ecosystems (Lai et al., 2012) if irrigation and fertilization practices increase the soil water and nutrient contents. Therefore, it is important to investigate soil respiration from farmlands in the arid region of China.

In agriculture ecosystems, soil respiration is affected by environmental variables (e.g., soil temperature, soil water content, air CO_2 concentration, soil physical and chemical properties) (Kou et al., 2007; Schlesinger and Andrews, 2000; Tong et al., 2017; Wang et al., 2003) and management practices (e.g., irrigation, fertilization and tillage) (Abdalla et al., 2011; Scheer et al., 2013; Schlesinger and Andrews, 2000; Shao et al., 2014). In arid and semi-arid agricultural regions, the application of plastic film has been applied to reduce soil evaporation

---

[*] Corresponding author.
E-mail address: zcy@ms.xjb.ac.cn (C. Zhao).

https://doi.org/10.1016/j.agrformet.2018.02.025
Received 5 September 2017; Received in revised form 20 February 2018; Accepted 22 February 2018

and consequently change the water use efficiency of plants (Chakraborty et al., 2008; Han et al., 2014). As this technology has been shown to increased crop productivity, the soil temperature and moisture likely increases soil respiration through enhanced CO_2 production via root and heterotrophic respiration (Chen et al., 2017; Liu et al., 2016b; Zhang et al., 2017a). The effect of this practice on soil biochemical processes depends on the air temperature and precipitation (Han et al., 2014), and thus, process-based models can be used to predict the effect of plastic mulching on soil respiration under different climate scenarios.

The denitrification-decomposition (DNDC) model was developed to simulate greenhouse gas emissions from agricultural soils (Li et al., 1992; Li et al., 1994; Li et al., 2017a; Zhang and Niu, 2016). Previous studies have used this model to simulate soil respiration from agricultural soils (Abdalla et al., 2014; Abdalla et al., 2011; Chirinda et al., 2010; Li et al., 2017b; Yu and Zhao, 2015) and to predict changes in soil respiration (Abdalla et al., 2014; Abdalla et al., 2011). This model, which was improved by Han et al. (2014), was recently used to simulate the effect of plastic mulching on soil biochemical processes (Han et al., 2014; Zhang et al., 2017c). Based on this improved model, Zhang et al. (2017c) predicted that the application of plastic film increased the resistance of both plant biomass and SOC to changes in air temperature and rainfall in the semi-arid region of China, and would likely influence changes in soil respiration under future climate scenarios. However, to our knowledge, few studies have evaluated the performance of the DNDC model in simulating soil respiration under plastic mulching.

Over the past 50 years, the air temperature and precipitation in the arid region of China (including Xinjiang, the northwestern section of Ningxia, the Hexi Corridor of Gansu Province, Qaidam Basin of Qinghai and the Alashan Plateau of Inner Mongolia) have increased by 1.5 °C and 37 mm, and this trend might continue in the future (Liu et al., 2017b). However, the future projections of climate scenarios (e.g., air temperature and precipitation) obtained from different climate models show variations (Liu et al., 2017a; Piao et al., 2010), resulting in different simulations of future soil respiration (Abdalla et al., 2014). Therefore, estimations of future soil respiration should consider the different climate models that have been developed. In this study, five climate models, which were utilized in the Inter-Sectoral Impact Model Inter-comparison Project (Warszawski et al., 2014) and had been validated by using data collected in the arid region of China (Wang et al., 2017), will be used to predict the effect of plastic mulching on soil respiration. The objectives of this study were to (1) evaluate the performance of the DNDC model in simulating soil respiration under plastic mulching; (2) assess the effect of plastic film mulching on the sensitivity of DNDC-simulated soil respiration to changes in climate variables; and (3) predict changes in soil respiration under different future climate scenarios.

2. Material and methods

2.1. Field experiment site

The experiment site was located at the Aksu National Experimental Station in an oasis farmland ecosystem in China (40°37′N and 80°45′E) with an altitude of 1028 m. Over the past 30 years (from 1986–2015), the annual mean temperature was 11.6 °C, and the annual mean rainfall was 63 mm. The mean atmospheric CO_2 concentration is approximately 380 ppm, and the mean nitrogen (N) concentration in rainfall is 3.8 ppm (Zhu et al., 2015). The soil at this site is gleyic solonchak (World Reference Base for Soil Resources). In the 0–10 cm layer, the soil texture is silt loam with 44% sand (0.02–2 mm), 50% silt (0.002–0.02 mm) and 6% clay ($<$ 0.002 mm), and the SOC, soil C/N ratio, bulk density and pH are 8.0 g C kg^{-1}, 11.9, 1.5 g cm^{-3} and 7.6, respectively. The arable fields are seeded with cotton (*Gossypium herbaceum* L.) at a density of 2.67×10^5 plants per hectare, with a maximum biomass for grain, straw and roots of 2.40, 4.96 and 0.91 Mg C ha^{-1}, respectively, and a C/N ratio of the biomass of 13, 34 and 50 for grain, straw and roots, respectively. The water requirement of the cotton is 250 g water per 1 g dry matter. The detailed measurement methods used for the soil and plants were described by Yu et al. (2017).

Table 1
Time of irrigation and fertilization practices during the experimental period.

Years	Irrigation	Fertilization
2014	3 July, 9 July, 20 July, 28 July, 6 August, 18 August, 26 August, 3 September	9 July, 20 July, 28 July, 6 August
2015	24 June, 5 July, 13 July, 21 July, 28 July, 4 August, 17 August, 25 August	5 July, 13 July, 21 July, 28 July

2.2. Field management and experimental design

The cotton fields were ploughed (30 cm deep) on 13 April 2014 and 15 April 2015. Urea (60 kg N ha^{-1}) and diammonium potash (20 kg N ha^{-1}) were incorporated into the soil with tillage as a starter fertilizer. Before tillage (half a month), approximately 15–20 cm of water was used in the flood irrigation practice to leach the accumulated salt in the topsoil (Han et al., 2015). During the experimental period (2014 and 2015), 320 mm of water was uniformly applied eight times by drip irrigation, and urea (320 kg N ha^{-1}) was uniformly dissolved in the water and applied four times. The time of irrigation and fertilization are provided in Table 1. Cotton was harvested on 15 November 2014 and 30 October 2015, and all of the residues were incorporated into the soil during the next tillage.

The field experimental site (10 m long and 6 m wide) included mulched and non-mulched treatments to investigate the influence of plastic mulching on soil respiration. Each treatment was replicated three times using a completely randomized design. In the mulched treatment, the ridge soil (1.0 m wide and 0.05 m high) was covered with plastic film (1.2 m wide and 0.02 mm thick) at the time of sowing, and the edge of the film was sealed under the soil. The furrow soil (0.5 m wide) of the mulched treatment remained uncovered. In the non-mulched treatment, both the ridge and the furrow soils remained uncovered. For each treatment, the soil respiration rates from the ridge and furrow sites were observed using the closed-chamber method. Each piece of equipment included a stainless-steel chamber and base. The detailed sampling method was described by Yu et al. (2017).

During the sampling period, the headspace gas (60 ml) was collected at 0, 10, 20, 30 and 40 min after chamber closure using a syringe, and the CO_2 concentrations were detected using a gas chromatograph (Agilent 7890A, Agilent, Palo Alto, CA, USA). Specifically, the CO_2 was first reduced to methane by a nickel catalyst and then detected by a hydrogen flame ionization detector (FID) at 375 °C. The soil respiration rate was calculated based on the linear or non-linear increases in the CO_2 concentration in the chamber (Wang et al., 2013). The cumulative soil respiration was estimated through a linear interpolation of the daily mean soil respiration and the number of days between samples and then summed over the experimental period. Because the cotton field included ridge (1.0 m) and furrow (0.5 m) soils, the total soil respiration (*Rs*) from the cotton field were calculated by the following mass balance:

$$R_s = R_{rs} \times 2/3 + R_{fs} \times 1/3 \tag{1}$$

where R_{rs} and R_{fs} are the soil respiration from the ridge and furrow soils, respectively. Moreover, the plant biomass, soil temperature and moisture were simultaneously measured, and the detailed information was described by Yu et al. (2017).