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Carbon exchange of a rainfed spring maize cropland under plastic film mulching with straw returning on the Loess Plateau, China

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A B S T R A C T

Increasing attention has been paid to the potential of croplands to mitigate rising atmospheric CO_2 concentrations by adopting appropriate cultivation practices. Plastic film mulching with straw returning to promote crop yields is widely used in rainfed agriculture; however, information about the effect of this practice on carbon exchange is limited. Eddy covariance measurements were used to investigate carbon fluxes in a rainfed spring maize cropland under plastic film mulching with straw returning on the Chinese Loess Plateau in 2013 and 2014. Carbon fluxes showed a clear seasonal variation, with the green leaf area index (GLAI) being the dominant control factor. The diurnal and seasonal ecosystem respiration (R_e) values were driven by gross primary productivity (GPP), and the daily R_e per unit daily GPP increased by 0.32 g C m^{-2} d^{-1}. The ecosystem apparent quantum yield (α), ecosystem maximum photosynthetic capacity (P_{max}), and ecosystem respiration rate at 10 °C (R_{10}) also showed clear seasonal variations, and the mean monthly α, P_{max}, and R_{10} per unit mean monthly GLAI increased by 1.44×10^{-2} μmol CO_2 μmol PAR^{-1}, 1.12 mg CO_2 m^{-2} s^{-1}, and 2.08×10^{-2} mg CO_2 m^{-2} s^{-1} respectively. The temperature sensitivity of ecosystem respiration was insensitive to GLAI, and ranged from 1.58 to 2.85, with the maximum value appearing in the non-growth seasons. Annual GPP values were 1547 and 1370 g C m^{-2} in 2013 and 2014, respectively, approximately 60% of which was lost through R_e, which resulted in annual net CO_2 uptakes of 618 and 540 g C m^{-2} in 2013 and 2014 respectively. Compared to the non-mulching spring maize field with straw returning, the spring maize field under plastic film mulching with straw returning was a stronger carbon sink (76 and 41 g C m^{-2} in 2013 and 2014, respectively). Plastic film mulching with straw returning is recommended as an effective approach to sequester carbon in rainfed spring maize cropland on the Loess Plateau and to mitigate greenhouse effects.

1. Introduction

Farming is the largest scale human activity in the world, and carbon in the agro-ecosystem is the most active part of the global carbon pool. Historically, massive conversions of native ecosystems to cropland caused a substantial reduction in soil carbon and large emissions of greenhouse gases, mainly through soil respiration (Robert and Saugier, 2003). However, agricultural management practices have changed markedly in China in recent decades, with straw returning, plastic film mulching, and increased fertilizer use more widely employed. There is an increasing understanding of the potential for croplands to sequester carbon to help mitigate the greenhouse effect and climate change (Béziat et al., 2009). A number of reports have shown a significant increase in the soil carbon stock with the use of different agronomic strategies (e.g., no tillage, straw returning, manure, and plastic film mulching) (Verma et al., 2005; Bernacchi et al., 2006; Ding et al., 2012; Buysse et al., 2013; Li et al., 2015).

By 2008, China was already ranked first in the world for ground film coverage area, with a total area of 15.613 million ha, accounting for about 13% of national arable land (Yan et al., 2010). Maize plantations cover around 33.43 million ha and account for the largest acreage of Chinese crops, including plastic film mulching spring maize (*Zea mays* L.) with an area 6 million ha (http://www.stats.gov.cn/ztjc/ztfx/fxbg/201112/t20111202_16150.html), which plays an important role in food security. The introduction of agricultural machinery and policy inducements in recent years has resulted in the widespread use of straw returning. And plastic film mulching with straw returning has been an important agronomic practice on the Loess Plateau. Scientific research has mostly focused on the effect of plastic film mulching with straw returning on yield increase and income growth (Liu et al., 2010; Li et al., 2012). Although some studies have investigated the influence of plastic film mulching with straw returning on soil respiration and soil

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organic matter (Okuda et al., 2007; Li et al., 2011; Li et al., 2015), limited information exists on carbon exchange in spring maize under plastic film mulching with straw returning at the ecosystem scale. Ecosystem-scale observations of CO_2 exchange are useful for understanding the influence of photosynthesis, respiration, and agronomic strategies on the carbon budget (Prescher et al., 2010).

The ecosystem apparent quantum yield (α) and the ecosystem maximum photosynthetic capacity (P_{max}) are important parameters for describing ecosystem photosynthetic activity and determining the shape of the light response curve (Lindroth et al., 2008; Yu et al., 2008; Béziat et al., 2009). The ecosystem respiration rate at 10 °C (R_{10}) and the temperature sensitivity of ecosystem respiration (Q_{10}) are important parameters for describing ecosystem respiration rate and determining the temperature response equation (Glenn et al., 2006; Fu et al., 2009; Zhou et al., 2009a). These photosynthesis and respiration parameters have great significance for carbon exchange, and are also often used to fill gaps in flux measurements (Han et al., 2014; Zhong et al., 2016). The seasonal variations of these parameters and their responses to abiotic factors (e.g., temperature, soil water content, and vapor pressure deficit) have been studied previously for a range of ecosystems (Zhang et al., 2006). However, most studies have focused on natural ecosystems (Zhang et al., 2006; Fu et al., 2009; Zhong et al., 2016), and studies on agro-ecosystems are still lacking. In addition, the effects of biotic factors, such as green leaf area index (GLAI), on these parameters have not been sufficiently studied (Lindroth et al., 2008).

The Loess Plateau, characterized by a semiarid monsoon climate, is an important rainfed farming region in northwest China (Liu et al., 2010). Spring maize is one of the most popular grain crops on the Plateau, accounting for 27.3% of the total agricultural area (Liu et al., 2010); however, drought and low air temperatures in April–June often result in poor plant establishment (Liu et al., 2009; Bu et al., 2013). Plastic film mulching with straw returning can promote spring maize growth in these early stages (Zhou et al., 2009b; Li et al., 2013), and is widely used on the Plateau. During the past two decades, eddy covariance technique has become the standard method for measuring trace gas exchanges between terrestrial ecosystems and the atmosphere (Taylor et al., 2013; Wang et al., 2015), as it can provide a long-term continuous and direct observation for trace gas fluxes without destroying underlying surface. This method was used to measure the carbon fluxes of spring maize cropland under plastic film mulching with straw returning on the eastern Loess Plateau in 2013 and 2014. Thus, the objectives of this study were: (1) to characterize diurnal and seasonal variations in carbon fluxes and to investigate how these are affected by the GLAI; (2) to characterize seasonal variations in photosynthesis and respiration parameters and to investigate how these are affected by the GLAI; and (3) to quantify the carbon balance of spring maize cropland under plastic film mulching with straw returning.

2. Materials and methods

2.1. Site description and measurements

2.1.1. Site description

The study was conducted in 2013 and 2014 at the Shouyang Scientific Observing and Experimental Station of the Dryland Agriculture and Ago-environment, Ministry of Agriculture, P.R. China, located in Jingshang town (37° 45′ N, 113° 12′ E, 1202 m a.s.l.), Shanxi Province in the eastern part of the Loess Plateau. The experimental region has a semiarid continental temperate monsoon climate, with a mean annual air temperature of 8.2 °C and a mean annual frost-free period of 150 days. The mean annual precipitation is 474.5 mm with > 70% occurring between July and September. The soil organic matter, total nitrogen, total phosphorus, and total potassium contents of top soils in our site are 9.00 g kg^{-1}, 0.79 g kg^{-1}, 0.72 g kg^{-1}, and 19.61 g kg^{-1}, respectively.

The cultivation method in the experimental field followed current

Table 1
Dry grain (D_g), dry cob (D_c), and exported carbon (C_e) in the spring maize field in 2013 and 2014.

Year	D_g (kg ha^{-1})	D_c (kg ha^{-1})	C_e (g C m^{-2})
2013	10,767	1507	552
2014	9924	1389	509

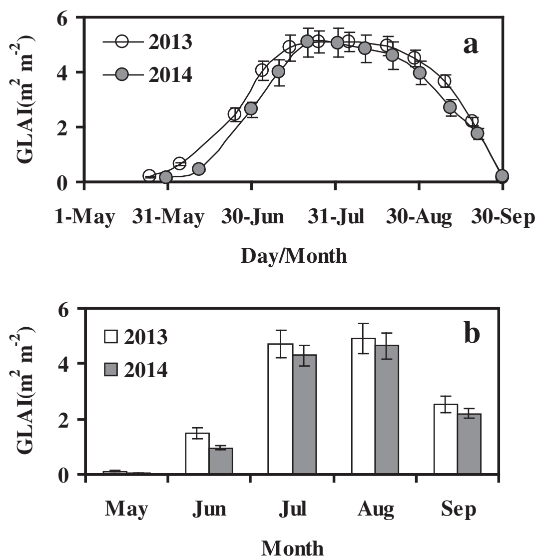

Fig. 1. Seasonal variations in (a) daily values and (b) mean monthly values of green leaf area index (GLAI) in 2013 and 2014.

typical farming practices of the region (Yan et al., 2010). N, P, and K fertilizers were applied to the field as a basal dressing at the rates used by local farmers (207 kg N ha^{-1}, 47 kg P ha^{-1} and 37 kg K ha^{-1}) prior to sowing. Spring maize was sown around 1 May, at a plant density of approximately 6.67 × 10^4 plants ha^{-1} and a plant spacing of 0.3 m, with the plastic film mulching area accounting for approximately 70% of the total. The plastic film was a kind of transparent polyethylene film with a thickness of 8 μm. The growth season of spring maize was from 1 May to 30 September, as spring maize matured before 30 September. All of the spring maize straw was chopped by automated machines and returned to the field at harvest time. The soil was completely covered by the straw during the non-growth season. The remainder of the straw that was undecomposed during the non-growth season and base fertilization was completely mixed with the soil through tillage in late April of the next year. The estimated annual carbon imported was 10.0 g C m^{-2}, as both fertilizer and seed.

2.1.2. Eddy covariance flux measurements

An eddy covariance system was installed in the center of a spring maize field (100 m × 260 m) in May 2011. The system height increased with crop growth, and kept approximately 1.3 m above the top of the canopy in accordance with an available fetch (~140 m) in the prevailing wind direction. The eddy covariance system consisted of a 3-D sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, UT, USA) and an open-path infrared gas analyzer (LI-7500, Li-COR Inc., Lincoln, NE, USA). Data were recorded at a frequency of 10 Hz on a data logger (CR5000, Campbell Scientific Inc.).

2.1.3. Other measurements

Air temperature (T_a) was recorded at 30-min intervals using a temperature sensor (HMP45C, Vaisala Co., Ltd., Helsinki, Finland) connected to a data logger (CR5000, Campbell Scientific Inc.). Photosynthetically active radiation (PAR) was measured using a quantum sensor (LI190SB, Li-COR Inc.), and recorded at 30-min