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Research paper

Does long-term plastic film mulching really decrease sequestration of organic carbon in soil in the Loess Plateau?

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ABSTRACT

Plastic film mulching (PM) is used extensively in China to increase the productivity of food crops, especially in the arid and semi-arid regions, although a recent concern is whether the practice decreases soil organic carbon (SOC). A process-based biogeochemical model applied in the Loess Plateau, where PM is widespread, examined the status of SOC over 30 years of maize cultivation with PM. The model explained 96% of the observed variance in SOC. The root mean square error was $0.39\ g\ kg^{-1}$, the mean absolute error was $0.32\ g\ kg^{-1}$, and the bias value from the SOC simulation was $-0.006\ g\ kg^{-1}$. The model's projections showed that PM has no significant impact on the overall average content of SOC across the entire study area compared to the fields without mulching, or control (CK), assuming that 5% of the crop residue was ploughed back into soil. However, based on individual simulation points in the 0–50 cm soil profile after 30 years of PM, 59.29% of the points, mainly on the western parts of the Loess Plateau, showed significantly higher SOC than that in CK, 8.30% showed significantly lower, and 32.41%, mainly on the south-eastern part of the Plateau, showed no significant difference between sites with PM and without it. Mulching increased the biomass, rhizodeposition, and the speed of turnover of SOC significantly, compared to the corresponding values in CK. High biomass in PM led to more carbon (C) being retained in soil and lowered the depletion of SOC. Ploughing the crop residues back into soil increased SOC, the greater the percentage of residue thus returned to soil, the higher the SOC. For a given residue return percentage, PM could increase more SOC than the CK. At 15%, which is the current average residue return ratio in the Loess Plateau, SOC levels remained stable or even increased in 77% of the study area if it adopted PM; in CK, the corresponding figure was only 63%. In regions such as the Loess Plateau where biomass is in great demand as a fuel or animal feed, PM provides greater biomass, which also means that more of it is available to be returned to soil—PM thus promotes the sequestration of SOC.

1. Introduction

Improving the productivity of smallholder farms offered the best chance to reduce poverty in developing countries (Larson et al., 2016). Plastic film mulching (PM), one of the most successful practices to increase crop production, is used throughout the world, specifically in the small household farmers (Gan et al., 2013; Lamont, 2005; Liu et al., 2009; Mo et al., 2017; Steinmetz et al., 2016; Zhou et al., 2009), and the cropped area under mulching worldwide is projected to grow by 5.7% annually until 2019 (Kasirajan and Ngouajio, 2012). Such mulch greatly reduces evaporation from soil, retains more moisture in the soil, and increases soil temperature throughout the growth period of a crop (Lament, 1993; Liu et al., 2014a), thereby providing more conducive conditions for seedlings and new shoots (Tarara, 2000; Zhou et al., 2009). Furthermore, PM controls weeds and other pests (McKenzie and Duncan, 2001); shortens the time taken for the development of fruits and seeds; increases yield; and prevents wind erosion of soil (Chalker-Scott, 2007; Lament, 1993; Li et al., 2004; Scarascia-Mugnozza et al., 2012).

However, higher soil temperature as a result of PM implies faster decomposition of soil organic carbon (SOC) (Trumbore et al., 1996), and field experiments confirm that soil respiration increases significantly because of mulching (Chen et al., 2015; Li et al., 2004; Liu et al., 2010; Zhang et al., 2015). In turn, this has led to increasing concern about the sustainability of soil following long-term PM (Gan et al., 2013; Steinmetz et al., 2016; Zhou et al., 2012). The SOC is one of

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the most important terrestrial pools of carbon (C), which is the result of a dynamic equilibrium between gains and losses of C. Normally, SOC is relatively dynamic and can be greatly influenced by agricultural practices, and small changes in SOC may potentially trigger significant changes in large-scale C cycling (Liu et al., 2006).

Thus, the balance of SOC is one of the major indicators of the sustainability of an agricultural ecosystem (Lal, 2004; Zhang et al., 2006). On the other hand, a few field studies found no significant difference in SOC between fields with PM and those without it (Liu et al., 2014b; Luo et al., 2015; Wang et al., 2016; Zhang et al., 2017), indicating that increased biomass due to PM offsets the loss of SOC due to greater mineralization. However, detailed information is not available on the process of SOC balance and on changes in SOC on a large (regional) scale, especially over longer time span, and this lack of information presents a challenge to evaluating the effects of PM on soil sustainability (Steinmetz et al., 2016).

It was against this background that the present study sought to obtain, through a process-based soil C model, detailed information on the dynamics of C pools under PM for 1) evaluating the long-term impacts of PM on the dynamics of SOC, 2) quantifying the changes in SOC under PM in different soil types and climatic conditions and examining the spatial heterogeneity on a regional scale, 3) and ascertaining whether increased inputs of C to soil can offset the increased mineralization of SOC as a result of higher soil temperature and moisture brought about by PM.

2. Method

2.1. Study area

The Loess Plateau, spread over approximately 64 million hectares, supports about 100 million people (Fig. 1) and is the major rainfed dryland farming region in China (Chen et al., 2015). The annual average rainfall is 412 ± 153 mm and ranges from 100 mm to 1000 mm; the annual average temperature is 8 ± 3 °C and ranges from −9 °C to 15 °C (Fig. 1). High evaporation has constrained agricultural production in the Loess Plateau for a long time. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) aridity index, which is based on precipitation (P) and potential evapotranspiration (PET) from the Penman ET model (Parr et al., 1990), arid zones are classified as follows in terms of the P/PET ratio: hyper arid (more than 0.03), arid (0.03 to less than 0.20); semi-arid (0.20 to less than 0.50), and subhumid (0.50 to less than 0.75). The Loess Plateau encompasses the last three of these zones, and most of the present study points were within the arid and the semi-arid zones (Fig. 1). Plastic film mulching is hugely popular in the Loess Plateau and recommended by the local government (Liu et al., 2014a; Ye and Liu, 2012; Zhao et al., 2014; Zhou et al., 2009). The wide variation in precipitation and temperature across the Plateau makes it the ideal region for evaluating the impact of PM on the balance of SOC with reference to dryland rainfed agriculture.

2.2. Data sets

2.2.1. Daily weather

data on daily maximum and minimum temperature and precipitation were part of the data from the China Meteorological Data Center (http://data.cma.cn). The data set, covering 2472 China National Metrological Stations at a spatial resolution of 0.5° × 0.5°, was processed with AUNSPLIN using the thin plate spline method. Data on daily radiation, wind speed, and humidity were part of the AgCFSR Climate Forcing Dataset (resolution, 0.25° × 0.25°). A detailed description of the AgCFSR data set can be found in Ruane et al. (2015).

2.2.2. Elevation

ASTER L1 B products of the study area were retrieved from https://lpdaac.usgs.gov/data_access/data_pool.

2.2.3. Soils

The data were based on the soil grid (Hengl et al., 2014) and can be downloaded from https://lpdaac.usgs.gov/data_access/data_pool.

2.2.4. Nitrogen deposition

The amounts of nitrogen (N) deposition from atmosphere were derived from the Global Maps of Atmospheric Nitrogen Deposition (Dentener, 2006).

2.3. Simulation scenarios

For the model, the most popular method of planting was assumed, namely equally ridges and furrows (ridges 55 cm wide and 15 cm tall) fully covered with plastic film, and the fertilizer dose was assumed to be

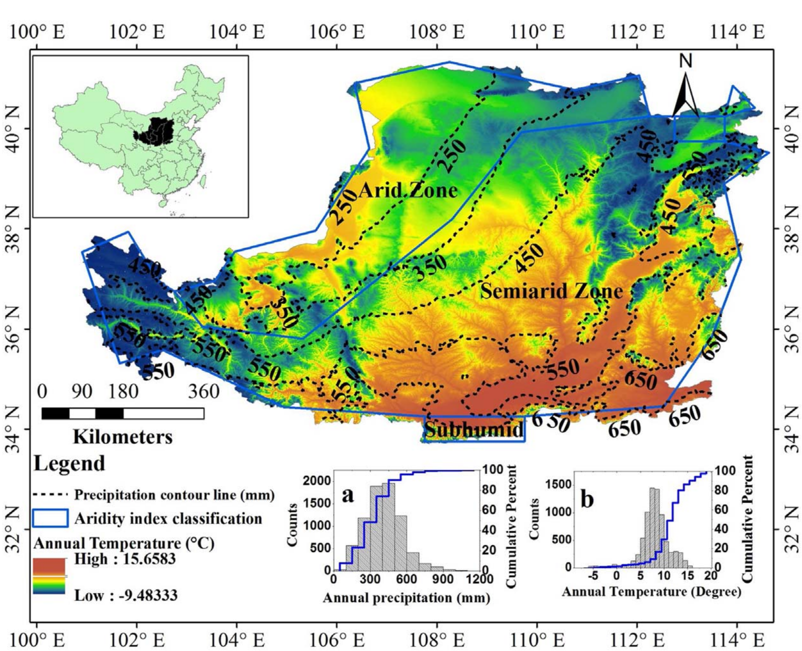

Fig. 1. Annual temperature (a), annual precipitation (b), and aridity across the Loess plateau. According to the UNESCO climatic aridity index classification system, which is based on precipitation (P) and potential evapotranspiration (PET) from the Penman ET model, arid zones are classified as follows in terms of the P/PET ratio: hyper arid (more than 0.03), arid (0.03 to less than 0.20), semi-arid (0.20 to less than 0.50), and subhumid (0.50 to less than 0.75). Only the last three of these zones are found in the Loess plateau.