



Original article

Sensitivity of soil organic carbon stocks and fractions to soil surface mulching in semiarid farmland

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ABSTRACT

There is little information regarding the impact of plastic film and gravel mulching on soil organic carbon (SOC) stocks and labile fractions in semiarid areas of northwest China. Based on a 4-year spring maize (*Zea mays* L.) field experiment at Changwu Agricultural and Ecological Experimental Station, we analyzed the SOC stock, labile SOC pools and the C management index (CMI) in the 0–20 cm and 20–40 cm layers. The three treatments included non-mulched (CK), gravel-mulched (GM) and plastic film-mulched (FM). After the 4-year duration, compared with the initial SOC stock, the SOC stock under GM decreased 0.97 Mg C hm⁻² whereas under FM increased 1.14 Mg C hm⁻² in the 20–40 cm layer. Across the 0–40 cm layer, the SOC stock under GM significantly decreased, whereas under FM demonstrated some tendency to increase. In contrast to the CK, the FM treatment significantly increased light fraction organic C (LFOC) content (density <1.7 g cm⁻³) by 17.2 mg kg⁻¹ in the 20–40 cm layer. Although, the FM treatment significantly decreased the CMI in the 0–20 cm layer, compared with the CK, but an increased trend of CMI in the 20–40 cm layer was observed. KMnO₄-oxidized organic C and LFOC were more sensitive than other C fractions in comparison of relative changes for labile SOC fractions. In conclusion, plastic film mulching could be the best option for sustainably enhancing crop productivity and maintaining soil quality in the semiarid regions of northwest China.

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1. Introduction

Soil contains the largest organic C pool, approximately 1550 Pg of C, in the global terrestrial ecosystems [1]. Concerns about the increasing atmospheric concentration of greenhouse gases, particularly CO₂, have enhanced the interest in soil C sequestration as a strategy to offset anthropogenic CO₂ emissions [2]. Globally, agricultural lands have the potential to sequester approximately 5500–6000 Mg CO₂-eq. yr⁻¹ by 2030 [3]. Therefore, keeping a satisfactory level of soil organic carbon (SOC) is significant for ensuring food security and mitigating climate warming.

The Loess Plateau has a typical semiarid monsoon climate [4], in which maize (*Zea mays* L.) is one of the most common grain crops; however, low air temperatures and drought during the early crop growth stage in the spring often result in poor crop yield [5].

Currently, gravel and plastic film mulching, which have been widely used in the arid and semiarid regions in China [6,7], may greatly improve crop yields and biomass due to increases in soil moisture and topsoil temperature [8]. Alleviating the hydrothermal limitations to growth by mulching, however risks depleting the SOC and reducing soil quality through increased SOC mineralization and microbial activity [9,10]. Wall et al. and Hou et al. found increasing soil temperature increased CO₂ emissions in cropland soils [11,12]. The SOC stock is the result of organic C inputs to and outputs from the soil. Plastic film mulching may increase the organic C input to the soil due to the increased root biomass [13]. However, very little information is available regarding the labile C pools and organic carbon stocks in gravel and plastic film mulching agroecosystems. A few studies reported that plastic film mulching resulted in significant decreases in SOC and increases in MBC and LFOC [9,10]. Wang et al. [14] found gravel mulching increased the SOC stock.

Because of high background C content, the effect of management practices on SOC contents, which vary both spatially and

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temporally [15], may not be detectable early. Labile SOC fractions, such as microbial biomass C (MBC), light fraction organic C (LFOC), water soluble organic C (WSOC), extractable organic C (EOC) and KMnO_4 -oxidized organic C ($\text{KMnO}_4\text{-C}$) have recently received more attention due to their sensitivity to management practices compared with total SOC [16]. In 1995, the C management index (CMI) was derived by combining labile and non-labile C fractions [17]. Subsequently, the CMI has been widely used as a sensitive indicator of the SOC variation rate in response to soil management changes [18]. Therefore, understanding the labile SOC pools, along with the SOC stocks and the CMI, is essential in determining the sustainability of an agroecosystem.

The objectives of this study were to (1) assess the impact of different mulching practices on labile C pools and SOC stocks, and (2) identify and quantify the interrelationships among different C fractions. This information will be useful for understanding the SOC dynamics and developing integrated management practices to improve the SOC in a spring maize cropping system in the semiarid regions of the world with a similar climate as that of northwestern China.

2. Materials and methods

2.1. Site description

This study was conducted from 2010 to 2013 at Changwu Agricultural and Ecological Experimental Station (35.28°N, 107.88°E, 1200 m altitude), which is located in a semiarid area on the Loess Plateau of China. The annual mean air temperature is 9.2 °C, and the average annual precipitation from 1957 to 2009 is 580 mm with 73% of this falling (425 mm) during the maize growth season. In contrast, the average annual evaporation from a free water surface is 1564.5 mm, with a ratio of free evaporation to precipitation of 2.7. The water table is at a depth of more than 60 m and thus, groundwater is unavailable for plant growth. The monthly precipitation and air temperature distributions were recorded throughout the year over the whole period of experiments. Two wet years occurred in 2010 and 2011 (496 and 487 mm) and one dry year in 2012 (363 mm), while the rainfall in 2013 fell in the normal range (421 mm) during the maize growth season. According to the Chinese Soil Taxonomy, the soils at this site are Cumuli-Ustic Isohumosols [19]. The soil properties at the top 20 cm were: bulk density 1.3 g cm⁻³, pH 8.4, organic C 8.2 g kg⁻¹, total N 1.05 g kg⁻¹, available phosphorus (Olsen-P) 20.7 mg kg⁻¹, available potassium ($\text{NH}_4\text{OAc-K}$) 133.1 mg kg⁻¹, and mineral N 28.8 mg kg⁻¹ in April 2009, prior to the start of the experiment.

2.2. Experimental design and field management

In this experiment, we applied three treatments, including non-mulched (CK), gravel-mulched (GM) and plastic film-mulched (FM), to maize plots. The treatments were applied to 56 m² (8 m × 7 m) plots arranged in a completely randomized block design with three replicates. The three treatments involved an alternating wide and narrow row spacing of 60 cm and 40 cm. Gravel (2–4 cm in size) and plastic film (0.005 mm thick, 1.2 m wide) were used to cover the soil in the GM and FM treatments, respectively, after the base fertilizer application and before sowing. After ridging the treatment plots, chemical fertilizers were broadcast over the soil at rates of 90 kg N hm⁻² in the form of urea (N 46%), 40 kg P hm⁻² in the form of calcium super phosphate (P_2O_5 12%), and 80 kg K hm⁻² in the form of potassium sulfate (K_2O 45%) as the base fertilizer application; the soil was then ploughed to mix the fertilizer into the subsurface. All of the plots were top-dressed twice with 67.5 kg N hm⁻² (urea, N 46%) during the jointing and

silking stages, using a hole-sowing machine. In each plot, the maize (*Zea mays* L.) was planted 5 cm deep at a density of 65,000 plants hm⁻², which was comparable to the densities in most farmers' fields.

2.3. Sampling and measurements

Soil was sampled in April before sowing and September after harvesting from 2010 to 2013. At each plot, soil cores were drilled randomly using a 4 cm diameter auger with three replications and then mixed together to form one composite sample for every soil depth (0–20 cm and 20–40 cm). Soil water content of each sample was measured after removing visible plant residues and sands, and then soil samples passed through a sieve by hand. The fresh sub-samples were refrigerated (0–4 °C) until the samples were measured for MBC, WSOC and EOC. The other sub-samples were air-dried and sieved through a 2-mm sieve and then analyzed for LFOC. Subsamples of <2 mm soil were then grounded to pass a 0.15-mm sieve to determine SOC and $\text{KMnO}_4\text{-C}$.

Bulk density was measured using a conventional core method. SOC content was determined by the wet oxidation method [20]. The soil organic C stocks (SOC, Mg hm⁻²) were calculated from the following equation:

$$\text{SOC stock (Mg hm}^{-2}\text{)} = \text{SOC (g kg}^{-1}\text{)} \times \text{bulk density (g cm}^{-3}\text{)} \\ \times \text{thickness (m)} \times 10$$

MBC was measured using a modified chloroform fumigation-extraction method [21]. Briefly, 12.5 g moist soil was fumigated with alcohol-free chloroform for 24 h at 25 °C. Excess chloroform was removed by repeated evacuation, and the soil then promptly extracted with 50 ml 0.5 M K_2SO_4 (soil/solution ratio of 1:4 w/v) on a rotary shaker at 220 r min⁻¹ for 0.5 h. After shaking, the supernatant was filtered using a Waterman membrane filter, filtrate was immediately frozen at -20 °C. Total organic C concentrations in the filtrate were measured using an automated total organic C analyzer (TOC-Vcph, Shimadzu, Japan). MBC was calculated by taking the difference between K_2SO_4 -extracted C of the fumigated and non-fumigated soils, and calibrated using the extraction efficiency factor of 0.45 [21].

LFOC used the density fractionation scheme as described by Gregorich and Ellert [22]: 20 g of air-dried soil were weighed into a 100-ml centrifuge tube to which was added 50 ml NaI solution at a density of 1.70 g cm⁻³. The solution was shaken at 250 r min⁻¹ for 1 h and then centrifuged at 3000 r min⁻¹ for 10 min. The clear supernatant was filtered under suction in a Buchner funnel with sintered glass. The light fraction organic matter retained on the 0.22- μm membrane filter was rinsed with 75 ml 0.01 mol L⁻¹ CaCl_2 and 150 ml deionized water and then transferred into a container. The precipitate at the bottom of the centrifuge tube was re-mixed with the NaI solution, shaken and centrifuged, and the supernatant filtered again to ensure efficient removal of the light fraction organic matter. The light fraction organic matter recovered from the two extractions was combined and then oven-dried at 65 °C for 24 h to determine the dry weight. The amounts of soil organic C in the light fraction were determined using a CHN elemental analyzer (Fisons Instruments, Germany).

WSOC was extracted from 20 g fresh soil with 40 ml deionized water (soil/solution ratio of 1:2 w/v) at 25 °C. After shaking at 250 r min⁻¹ for 0.5 h and then centrifuging for 10 min at 8000 r min⁻¹, the supernatant was filtered using a 0.45- μm membrane filter, and then filtrate was immediately frozen at -20 °C [23]. EOC was extracted from 10 g of fresh soil with 50 ml 0.5 M K_2SO_4 (soil/solution ratio of 1:5 w/v) at 25 °C. After shaking

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