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Effects of water management with plastic film in a semi-arid agricultural system on available soil carbon fractions

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A B S T R A C T

There is little information regarding the sustainability of the high yield agroecosystem with double ridges and furrows mulched with plastic film in semi-arid areas. In this study, we explored the sustainability of this agroecosystem with different mulching time during two growing seasons over 2006 and 2007. Three treatments were designed: (i) plastic film mulching applied at sowing and film removed at harvest (CK); (ii) mulching applied 30 days before sowing and removed at harvest (M1); and (iii) mulching applied at sowing and film left on field after harvest and used continually for mulching in the second season (M2). Microbial biomass C (MBC) and ratio of MBC to soil organic C (SOC) (MBC/SOC) were higher in M1 and M2 than in CK in 2007 growing season. The reduction rates of the ratios of light fraction of organic C (LFOC) to SOC (LFOC/SOC) with sampling dates were 0.0020, 0.0047 and 0.0045 for CK, M1 and M2, respectively. A larger value means a faster reduction rate of LFOC/SOC with sampling dates, and implying farming system would face a higher unsustainable risk. MBC correlated negative significantly with LFOC ($R = -0.939$, $P = 0.0001$) and mineral N ($R = -0.835$, $P = 0.0007$) due to low soil C pool. Accordingly, film mulched ridge and furrow system would threaten the sustainability of soil ecosystem via MBC increase a semi-arid agroecosystem. The practices of mulching applied 30 d before sowing (M1) and use of plastic film once every two years (M2) lead to increased environmental risk for the farming system.

In semi-arid areas, crop productivity is generally low, and it is difficult to maintain soil quality [2,8]. Recently, a method using double ridges and furrows mulched with plastic film for micro-catchment water harvesting has been popularized in dryland for spring maize cultivation, and this cropping pattern can significantly enhance maize grain yields compared to the conventional plastic-covered rainfall harvesting system [15]. Increased yield in response to film mulching is largely attributed to the increased soil temperature and improved water availability [15], which directly changes soil biological characteristics and fertility. Li et al. [6] reported that film mulching with spring wheat promoted microbial biomass C (MBC), but decreased soil organic C (SOC). The use of double ridges and furrows mulched with plastic film during maize production provides an excellent opportunity to enhance crop production, which may result in greater amounts of crop residue returned to the soil and improved soil quality.

We found that this technique improved soil water content in 0–120 cm soil layer, and significantly increased grain yield leading to soil water depletion in 140–200 cm soil layer. The soil water deficiency in 140–200 cm soil layer could be replenished by leaving plastic film mulch on the soil surface during the non-growing season [7]. However, little is known about the effects of high crop production with different mulching time in response to this new planting pattern on soil properties. Therefore, the objectives of this study were to: (1) investigate the relationship between soil carbon forms and soil nutrients; (2) and assess the sustainability of this micro-catchment tillage system.

The field experiment was conducted from March 2006 to September 2007 at the Semiarid Ecosystem Research Station of the Loess Plateau (36°02′N, 104°25′E, 2400 m above sea level), Lanzhou

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University. The description of the study site and methods has been published in a previous paper [7], and only relevant modifications will be described in this paper. Prior to the experiment in 2005, the site was planted with filed pea, followed by a fallow of 60 days before the experiment was designed. The experiment included three treatments: (i) mulching at sowing, and the plastic film was removed by hand at harvest every year (CK); (ii) mulching applied 30 days before maize sowing, the plastic film was removed by hand at harvest every year (M1); and (iii) mulching at sowing, and the plastic film was left in the field after harvest in the first year and was used for mulching in the second year (M2). When experiment was started, the same quantity of chemical fertilizer (167 kg N ha^{-1} and 51 kg P ha^{-1}) and donkey manure (1.5 t ha^{-1}) were applied to the top 20 cm by rotary tillage and harrowed for all treatments. In each plot, three soil cores (diameter 8 cm and height 20 cm) of depth 0–20 cm were taken randomly before building up ridges and furrows in March 2006, and in the middle between two plants of the furrows at harvesting in 2006 and sowing and harvesting in 2007. In order to facilitate tillage, the roots for CK and M1 were removed before the ridge and furrow system was built.

Soil organic C (SOC) and mineral N (MN) data have been reported in a previous paper [7]. Soil total nitrogen (TN) was measured by dry combustion using a CHNS-analyzer.

The density fractionation scheme for light used the method described by Gregorich and Ellert [1]. During fractionation, 25 g of air dried soil (<2 mm) were shaken with 50 ml of NaI solution (sp. Gr. = 1.70) for 60 min. After centrifugation, the supernatant was passed through a Millipore filter (0.45 μm) and the light fraction was collected. The soil residue in the centrifuge was extracted again with NaI and the additional light fraction was collected. The light fraction was oven-dried at 60 °C of 72 h. The concentration of organic C was determined by dry combustion using a CHNS-analyzer at 450 °C.

To determine MBC and microbial biomass N (MBN), samples were brought to the laboratory and stored at 4 °C for up to 10 days before analysis. Soil MBC and MBN were determined using fumigation extraction and assuming a K_{EC} and K_{EN} factor of 0.25 [9] as the difference between C and N extracted with 0.5 M K_2SO_4 through chloroform-fumigation and that from unfumigated samples. Organic C and total N in the extracts were measured using a multi N/C 3100 analyzer (Jena, Germany).

Analysis of variance (ANOVA) and correlation significance (R, correlation coefficient and p, probability) were conducted using the SPSS package (version 16.0; SPSS Inc., Chicago, IL). Comparisons were made by the least significant difference (LSD) at $p < 0.05$.

In the 2006 growing season, no significant difference of MBC or MBC/SOC ratio was observed in all treatments at sowing and harvest (Fig. 1a and b). In the 2007 growing season, MBC content in M1 and M2 was significantly higher than that in CK at sowing and harvest 2007. During the 2007 growing season, a higher ratio of

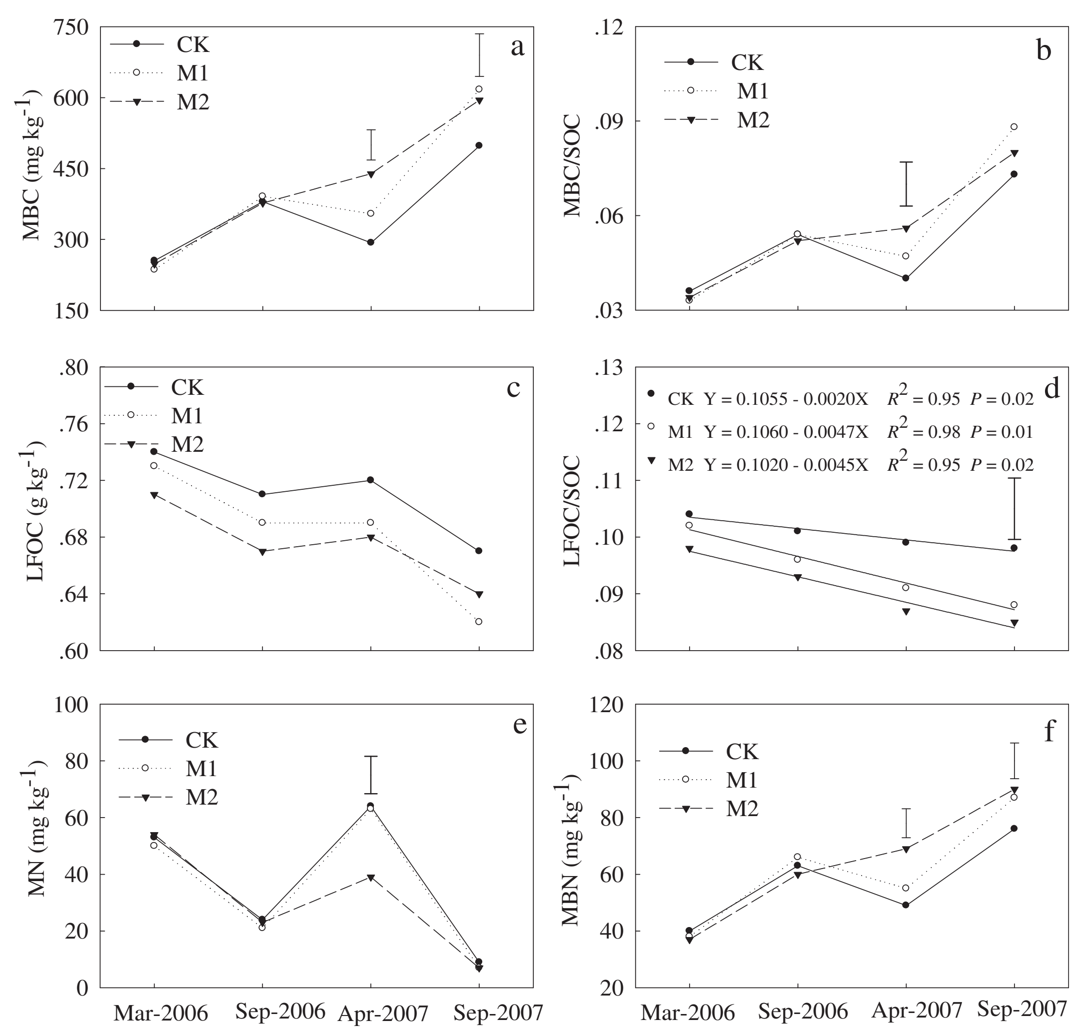

Fig. 1. Soil microbial biomass C (MBC), the ratio of MBC to soil organic C (SOC) (MBC/SOC), soil light fraction organic C (LFOC), the ratio of LFOC to SOC (LFOC/SOC), soil mineral N (MN) and soil microbial biomass N (MBN) in the 0–20 cm soil layer for maize plants grown with plastic mulches in various treatment groups. Vertical bars are the LSD at $P \leq 0.05$.