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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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ABSTRACT

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

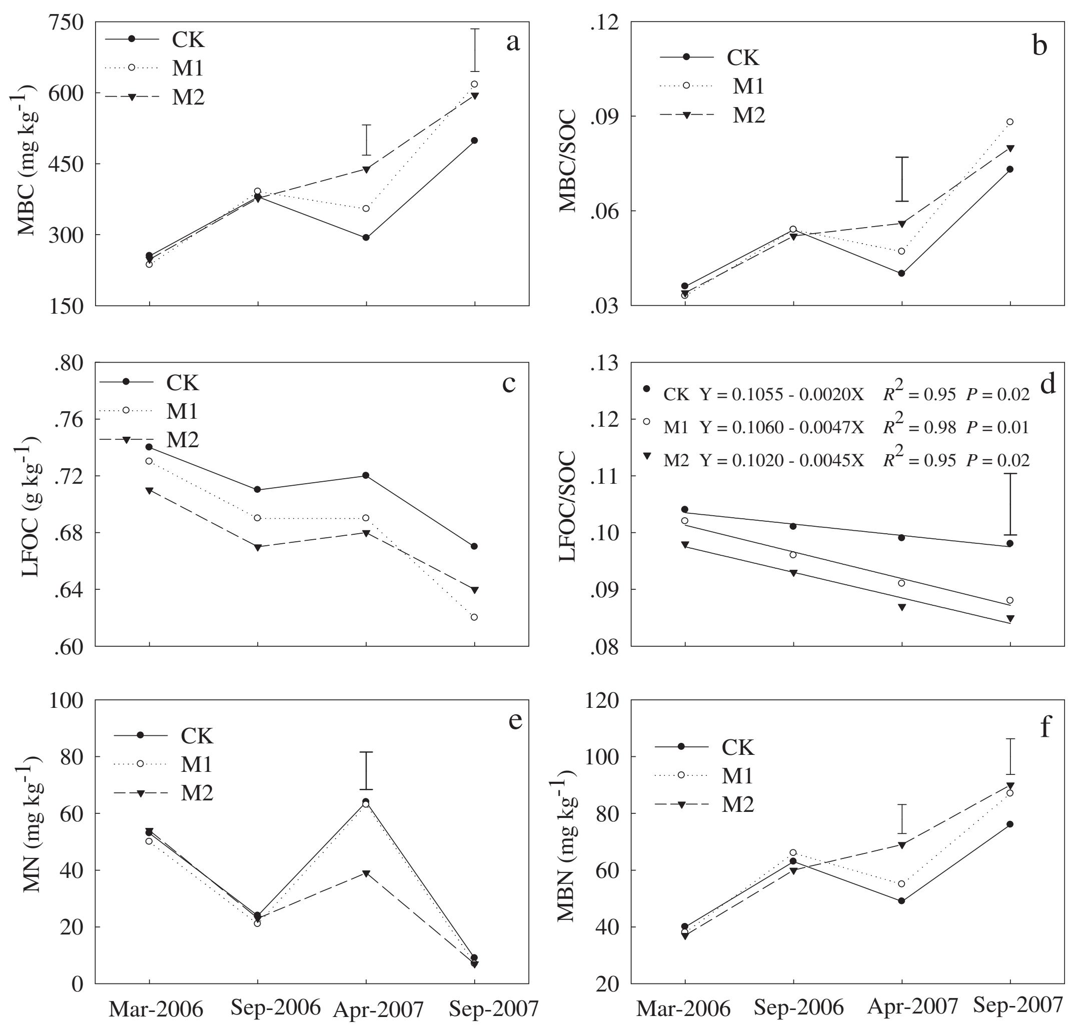

Fig. 1. Soil microbial biomass C (MBC), the ratio of MBC to soil organic C (SOC) (MBC/SOC), soil light fraction organic C (LFOC), the ratio of LFOC to SOC (LFOC/SOC), soil mineral N (MN) and soil microbial biomass N (MBN) in the 0–20 cm soil layer for maize plants grown with plastic mulches in various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

MBC/SOC was also observed for M1 and M2 than for CK at sowing 2007. MBC was significantly negatively correlated with LFOC ($R = -0.939$, $P = 0.0001$), MN ($R = -0.835$, $P = 0.0007$) for 2 years (Table 1). Li et al. [6] reported that, film mulching promoted MBC, and that topsoil moisture and temperature conditions played important roles in the changes in soil MBC. In our experiment, MBC was higher in M1 and M2 than in CK which largely due to increase of soil water availability and temperature during the early growing period as reported previously [7]. In April 2007, soil temperature (10 cm) was higher in M1 and M2 than in CK by 4.9 °C and 1.8 °C, respectively; soil water content in 0–20 cm soil layer was higher in M1 and M2 than in CK by 16.4% and 22.9%, respectively [7]. In 2006, there was no significant difference in MBC among all the treatments due to severe drought stress. In 2007, increased soil water availability and temperature in M1 and M2 by plastic film mulch during the non-growing season led to significant increase of MBC. The significant increase of MBC in M1 and M2 compared to CK led to a higher ratio of MBC/SOC in M1 and M2 than in CK. And the MBC/SOC ratio generally ranges from 0.01 to 0.04 in this region [4,11]. In the present study, it ranged from 0.03 to 0.09 depending on how long the mulch material stayed in place, which improved with the increase of mulching time. In this study, MBC changed first, and MBC can be as a sensitive indicator of soil quality with ridge–furrow and plastic-mulching tillage. Li et al. [6] reported that a significant negative correlation was found between MBC and SOC of film mulching in semi-arid agricultural systems. This interpretation is further supported by the negative correlation between MBC and LFOC in the present research.

The light fraction of organic C (LFOC) content in all treatments decreased in growing season during each year although the difference in LFOC between treatments was not significantly (Fig. 1c). The LFOC/SOC ratio in all treatments decreased with sampling date (Fig. 1d). The reduction in rates of the ratios of LFOC/SOC with sampling dates were 0.0020, 0.0047 and 0.0045 for CK, M1 and M2, respectively, and a larger value means a faster reduction rate of LFOC/SOC, implying that farming system would face a higher unsustainable risk. The light fraction of soil organic matter is important for the turnover of organic matter in farming soils because it serves as a readily decomposable substrate for soil microorganisms, and is a short-term reservoir of plant nutrients [1]. Generally, MBC was significantly positively correlated with LFOC in no-mulched system [5,13], and the negative correlation between MBC and LFOC is not documented in mulched system. However, in the present study, some unique processes in our experimental conditions, we found that MBC was significantly negatively correlated with LFOC. Wang et al. [10] reported that mulching decreased pentose and hexose levels in soil. Taken together, these findings indicate that film mulching in the farming system can enhance decomposition of the readily decomposable substrate of SOC, and lead to the decrease of LFOC/SOC. We also found that LFOC/SOC ratios decreased quickly with increase of mulching time by improving soil water content and temperature. In this region, the no-film mulched system for maize had no obvious effects on SOC and LFOC largely due to low microbial biomass activities compared to film mulched system [12]. Zhou et al. [14] reported that soil LFOC of can maintain balance when 5 t manure ha^{-1} was input in agroecosystem with furrow-ridge mulched with plastic film. In this study, SOC had no obvious changes in all treatments with ridge–furrow and plastic-mulching tillage [9], but LFOC decreased due to the increase of MBC (i.e., significant negative correlation was found between MNC and LFOC), which led to the decrease of LFOC/SOC. The decrease of LFOC or LFOC/SOC could be as a precursory signal of decrease of SOC. In this study, we found that agroecosystem with plastic film for maize had no significant effects on SOC, but SOC in the 0–20 cm layer was higher in M2 than in CK and M1 [7], which was largely duo to the root residues of maize in M2 were left in furrows after the first year which contributed organic matter to the SOC pool.

Table 1
Correlation coefficient (R) and significant level (P) between microbial biomass carbon (MBC) and soil properties.

Year		LFOC	MN	SOC	TN
2006	R	−0.768	−0.988	−0.356	−0.432
	P	0.0746	0.0002***	0.4886	0.3919
2007	R	−0.976	−0.947	−0.311	−0.772
	P	0.0009***	0.0042**	0.5480	0.0719
Two years	R	−0.939	−0.835	−0.017	−0.052
	P	0.0001***	0.0007***	0.9571	0.8736

LFOC: light fraction of organic carbon; MN: soil mineral N; SOC: soil organic C; TN: total N.
*, **, *** mean $P \le 0.05$, $P \le 0.01$, $P \le 0.001$, respectively.

In the 2006 growing season, no significant difference of MN or MBN was observed in all treatments at sowing and harvest (Fig. 1e and f). During the 2007 growing season, the MN content was significantly higher in CK and M1 than in M2 at sowing. During the 2007 growing season, the MBN content was significantly higher in M2 than in CK at sowing and harvest in 2007. In 2006, there was no significant difference in N uptake by maize [7] and activity of microorganisms among all the treatments, and correspondingly no significant differences in soil MN was observed between treatments. At sowing 2007, the activity increase of microorganisms in M2 compared to CK and M1 led to much more MN transformed into MBN, and decreased soil MN content. Maize has a high demand for N resources [3]. The mineral N content in all treatments in the present study decreased rapidly during each year (Fig. 1e). The decreasing content of mineral N in soil during the growing season is largely due to the activity increase of microorganisms and plant growth. This interpretation is further supported by the negative correlation between MBC and MN in the present research.

In conclusion, MBC correlated negative significantly with LFOC and MN of the high yield agroecosystem with ridges and furrows mulched with plastic film. This technique is challenges in maintaining soil fertility due to exhaustion risk of LFOC and soil N. The practices of mulching applied 30 days before sowing (M1) and use of plastic film once every two years (M2) lead to increased environmental risk for the farming system. Farmers should be encouraged to apply more manure to enhance the sustainability of this tillage system.

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