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Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogen fractions, crop yield and water use efficiency in the Loess Plateau, China

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ABSTRACT

A field experiment was conducted in the Loess Plateau of Northwest China to study the effects of plastic film mulching and straw mulching on soil water, soil organic carbon (SOC), total nitrogen (TN), microbial biomass carbon (MBC) and nitrogen (MBN), dissolved organic carbon (DOC) and nitrogen (DON), crop yield and water use efficiency under winter wheat (*Tricicum aestivum* L.)—summer maize (*Zea mays* L.) double-cropping system conditions using the following three cultural practices: (i) traditional plough with no mulching (CK), (ii) traditional plough with plastic film mulching (PM), and (iii) traditional plough with straw mulching (SM). Soil water contents were measured by the gravimetric method. SOC was determined using the dichromate oxidation method. TN was analyzed by the Kjeldahl method. MBC and MBN were determined using the chloroform fumigation extraction method. DOC and TDN were determined following Jones' procedures proposed by Jones and Willett (2006). The results showed that soil water was higher under the PM treatment than under the SM treatment and mainly changed in the upper 60 cm soil layer. Compared with the CK treatment, the concentrations of SOC and TN under the SM treatment were increased by 16.9% and 7.7% at the 0–10 cm soil depth, respectively, and the PM treatment had the similar SOC and TN concentrations. Compared with the CK treatment, soil C:N ratio was increased under the SM treatment by 6.2% ($P < 0.05$), and that under the PM treatment was decreased by 5.2% ($P < 0.05$) after three years. The concentrations of MBC under the PM and SM treatments were significantly increased by 42.0% and 24.1%, respectively, and MBN under the PM treatment was significantly increased by 5.6% at 0–10 cm soil depth after the maize season. Compared with the CK treatment, DOC was significantly increased by 21.0% under the SM treatment and decreased by 13.1% under the PM treatment, and DON was significantly increased by 10.5% under the SM treatment and decreased by 4.3% under the PM treatment at the 0–10 cm soil depth after the maize season. Relative changes of labile soil organic carbon and nitrogen fractions were more sensitive than that of SOC and TN. The relative decline or increase of labile soil organic carbon and nitrogen fractions was on average almost 13.6% for the mulching practices. Compared with the CK treatment, the average maize yields under the PM and SM treatments were increased by 26.4% and 9.8%, and the average wheat yields under the PM and SM treatments were increased by 21.3% and 7.4%, respectively. The average water use efficiencies under the PM and SM treatments were 24.5%, 8.8% in winter wheat and 22.9%, 6.3% in summer maize higher than that under the CK treatment, respectively. Our results suggested that plastic film mulching could be used as an effective practice to improve low soil quality with adequate nitrogen and increase crop yield and water use efficiency in the Loess Plateau, China.

1. Introduction

Different cultural practices may have different effects on the soil water and soil quality, and these effects may vary with soil type and climatic conditions (Lal, 2004; Huo et al., 2017). In the Loess Plateau of Northwest China, maize and wheat are both one of the most common

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grain crops (Li et al., 2004; Bu et al., 2013). However, soil degradation, inefficient water use, poor soil quality, and low-temperature stresses are the major constraints on crop production in this region (Fan and Zhang, 2000; Bai et al., 2009; Liu et al., 2009; Liang et al., 2010; Gao et al., 2016, 2018). Therefore, a number of techniques, including straw mulching, plastic film mulching, and rainwater harvesting, have been widely used in this region to improve soil quality and crop growth environments, thereby increasing crop yields (Li et al., 2004; Zhang et al., 2009; Liu et al., 2010; Bu et al., 2013; Li et al., 2013a,b).

In recent years, the practice of returning crop straw to the field has been widespread in winter wheat-summer maize double-cropping system in northwest China. This is mainly due to the increased use of machinery that leaves the crop straw on the land in response to a ban on straw burning made by the Chinese government. A lot of crop straw is burned directly and this has caused serious environmental pollution in the last decade (Xiao, 2012). Straw mulching is one practice for effective disposal that can decrease air pollution and provide soil organic matter (Soon and Lupwayi, 2012). Meanwhile, straw mulching can reduce evaporation loss from the soil surface, protect the surface from direct strike of raindrops, enhance soil aggregation, and promote biological activity (Salinas-Garcia et al., 2001; Blanco-Canqui and Lal, 2007; Chen et al., 2007; Blanco-Canqui and Lal, 2009; Sharma et al., 2011). Straw mulching can keep the soil warmer in winter and cooler in summer as well as reduce soil temperature oscillation (Chen et al., 2007). However, some researches present that low soil temperature caused by straw mulching froze wheat seedlings and roots during the winter, thereby negatively influenced germination and tillering (Gao et al., 2009). Therefore, straw mulching has not always been shown to increase, but decrease yields (Bonfil et al., 1999; Wang et al., 2002; Taa et al., 2004). Currently, plastic film mulching is widely used to increase soil temperature and reduce soil evaporation in vegetable and crop production in Northwest China. It is becoming a well-evolved technique for agriculture in arid, semiarid and sub-humid areas, especially where irrigation is not available and spring temperature is low (Dong et al., 2009). Plastic film mulching can increase topsoil temperature and prolong the reproductive growth period, which in turn enhances grain yield (Wang et al., 2009; Li et al., 2013a,b). However, the increases in both soil water and temperature can change the soil biological characteristics and may negatively impact on soil quality and sustainability (Li et al., 2004). It is known that the release of soil nutrients through decomposition of soil organic matter by microbes plays an important role in soil quality (Li et al., 2004). Therefore, it is necessary to critically examine the effects of straw mulching and plastic film mulching on soil organic matter to assess the changes in soil quality.

Soil organic carbon (SOC) and total nitrogen (TN) play a crucial role in the soil quality and fertility (Bauer and Black, 1994; Monaco et al., 2008; Zhao et al., 2015) because it significantly affects soil physical, chemical and biological properties, which can affect crop productivity and agro-ecosystems (Sainju et al., 2008). Maintenance of satisfactory level of SOC and TN are necessary for crop productivity and sustainable agro-ecosystems. However, it is difficult to detect the changes of SOC and TN in response to management practices in the short-term (Haynes, 2005; Gong et al., 2009). In contrast, labile soil organic carbon and nitrogen fractions (i.e., MBC, DOC, MBN, and DON) that turn over quickly can respond more rapidly to soil management than SOC and TN (Haynes, 2005; Schimel et al., 2007; Plaza-Bonilla et al., 2014). Therefore, SOC, TN, MBC, MBN, DOC and DON can be used to assess the effects of agricultural management practices on soil quality (Bremer et al., 1994; Gregorich et al., 1994; Dong et al., 2009; Plaza-Bonilla et al., 2014). Mulching practices may affect soil organic matter through decomposition and soil moisture preservation (Youkhana and Idol, 2009). However, little is yet known about the effects of different mulching practices on soil organic carbon and nitrogen fractions and crop yields in winter wheat-summer maize double-cropping system. In this study, we assumed that soil water, soil organic carbon and nitrogen fractions as well as crop yields would be affected by different mulching practices in winter wheat-summer maize double-cropping system. Therefore, the overall objectives of this study were to: (1) assess the effects of straw mulching and plastic film mulching practices on crop productivity in the Loess Plateau of Northwest China; (2) quantify SOC, TN, and labile soil organic C and N contents after 3-year field experiment to assess different mulching practices.

2. Materials and methods

2.1. Experimental site

Field experiments using a winter wheat-summer maize double-cropping system were conducted from June 2013 to June 2016 at the irrigation experimental station of the Key Laboratory of Agricultural Soil and Water Engineering sponsored by the Ministry of Education (34°18′N, 108°04′E, 506 m ASL) in Yangling, Shaanxi, China. The experimental site is located in the southern region of the Loess Plateau and belongs to a typical dry semi-humid area in northwest China. The average annual precipitation is 638 mm, with nearly 60% falling between July and October. The average annual sunshine hour is 2196 h, and the average annual air temperature is 13 °C. The precipitation distribution and daily mean air temperature were recorded throughout the year over the whole period of experiments (Fig. 1). The experimental soil was a silt clay loam with a mean bulk density of 1.45 g cm^{-3} and contained 11.17 g kg^{-1} total carbon and 0.95 g kg^{-1} total nitrogen in the 0–100 cm soil layer. The groundwater level was approximately 50 m.

2.2. Experimental design

The experimental field was cultivated with a winter wheat and summer maize double-cropping system for 20 years prior to the establishment of this experiment. This experiment had three treatments: (i) traditional plough with no mulching (CK), (ii) traditional plough with plastic film mulching (PM), and (iii) traditional plough with straw mulching (SM). The CK treatment comprised a flat, non-mulched plot. Winter wheat straw (3–5 cm in length) was applied at the rates of 4.0 t ha^{-1} in the summer maize plot and summer maize straw (3–5 cm in length) was applied at the rates of 4.0 t ha^{-1} in the winter wheat plot after the seeds were sown in the SM treatment. Plastic film (0.005 mm thick, 1.7 m wide) was mulched in the winter wheat and summer maize plots by hand after the seeds were sown in the PM treatment. The three treatments were arranged into a randomized complete block design with three replications. Each plot was 5 m long and 4 m wide. The chemical fertilizers consisted of 120 kg N ha^{-1} as $CO(NH_2)_2$ and 54 kg P ha^{-1} as Ca $(H_2PO_4)_2$ for maize and wheat, respectively, and were applied to the upper soil layer (0–20 cm) by rotary tillage for three treatments. In order to facilitate tillage, the roots for each plot were removed when the crop was harvested.

Maize seeds (cv.Qinlong-11) were sown at a density of 50,000 plants ha^{-1} on June 9, 2013, June 20, 2014, and June 15, 2015 after a rotary tillage, and the crops were harvested on September 28, 2013, October 12, 2014, and October 7, 2015. Three treatments involved alternating wide and narrow row spacing of 60 cm and 30 cm. The plots were irrigated with 80 mm water in 2013 due to low precipitation and not irrigated in 2014 and 2015. Wheat seeds (cv.Xiaoyan-22) were sown at a density of 150 kg ha^{-1} on October 16, 2013, October 18, 2014, and October 19, 2015, using a rotary tillage, and the crops were harvested on June 8, 2014, June 6, 2015, and June 5, 2016. Winter wheat was planted with 25 cm wide row space. The plots were irrigated with 60 mm water during the 2013–2014 and 2014–2015 growing seasons due to drought stress and not irrigated during the 2015–2016 growing season.