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Buried straw layer plus plastic mulching improves soil organic carbon fractions in an arid saline soil from Northwest China

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ABSTRACT

Salt stress has been increasingly constraining crop productivity in arid lands of the world and there is some evidence that a combination of straw layer burial and plastic film mulching alleviates salt stress and increases microflora diversity in a saline soil. However, their impacts on soil organic C (SOC), especially its active fraction are not well documented. We studied the combined effects of burying straw layer and plastic mulching on SOC, microbial biomass C (MBC) and dissolved organic C (DOC) using the following four treatments: deep ploughing with no plastic film mulching (CK); deep ploughing with plastic film mulching (PM); buried maize straw layer with no mulching (SL); and buried maize straw layer plus plastic film mulching (PM + SL). Compared with CK and PM, the PM + SL and SL treatments significantly enhanced the allocation of SOC to the 20–40 cm soil layer, due to an adequate supply of organic carbon from straw incorporation; the SOC value under PM + SL significantly decreased in the topsoil (0–20 cm) after 4 years, while that under CK and SL was little altered. After 4 years, the SOC under PM + SL and SL treatments increased by 5.84 and 10.78% ($P < 0.05$) in the 0–40 cm soil layer but that under PM decreased 6.79% ($P < 0.05$) while that under CK changed little. Although PM + SL and SL had much higher SOC at the 30–40 cm layer than CK and PM, the straw effect on soil layers greater than 40 cm was not significant. The increase in SOC within the entire 60 cm soil layer (from 5.01% in 2013 to 10.64% in 2014) under PM + SL was more pronounced. PM + SL also showed the highest contents of MBC and DOC due to the combined effect of plastic mulching and straw layer. The effect of straw burial on the MBC and DOC was more significant than that of plastic mulching, but the increase in MBC under PM + SL, SL and PM decreased with time, possibly because of the combined effects of water, heat and salinity as well as the increased stability of soil aggregates. The DOC under PM + SL and SL was basically stable compared with that under CK and PM. Significant positive correlations ($P < 0.01$) were observed between SOC and MBC and between SOC and DOC. Soil temperature and the difference in salt content at sowing and maturity had significant ($P < 0.01$) positive correlations with SOC and MBC, but soil water showed significant ($P < 0.01$) negative correlations with all the carbon fractions. Overall, the combined use of buried straw layer with plastic mulching could be a practical option for increasing the SOC in an arid saline soil.

1. Introduction

Different cultural practices may have different effects on the soil carbon (C) cycle, and these effects may vary with soil type and climatic conditions (Lal, 2004). Saline soils are widespread throughout the world and occupy about 400 million ha (FAO, 2008). About 20% of the world's irrigated land especially in arid and semi-arid regions, is salt-affected and/or irrigated with water containing elevated salt levels (Qadir et al., 2008). Saline soils have lower soil organic C (SOC) concentrations and crop yields than non-saline soils (Pankhurst et al., 2001). For example, the SOC concentration in surface arid saline soil is 5.8 g kg^{-1}, which is only 40% of that of other agricultural soils (Wang et al., 2004). The poor productivity of saline soil because of its large salt content, poor structure and porosity limits further C accumulation. The addition of organic materials such as farmyard manure, crop straw

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or compost is a common practice to alleviate the adverse effects of salinity in agro-ecosystems through beneficial physico-chemical changes in salt-affected soils, thereby improving soil productivity (Tahir et al., 1991; Gaffar et al., 1992; Liang et al., 2005; Yadvinder-Singh et al., 2005).

Soil microorganisms play key roles in organic matter decomposition and biogeochemical cycling of soil nutrients in ecosystems (Leininger et al., 2006; Cusack et al., 2011). Salinity may alter soil pH and other physicochemical properties, thereby affecting microbial growth and biochemical transformations of added plant and native C in soil (Nelson et al., 1996; Pathak and Rao, 1998; Green et al., 2004; Nachimuthu et al., 2007). Many studies reported that C mineralization reduced with increasing salinity due to decreasing microbial activity (Laura 1974, 1976; Sarig et al., 1993; Luna-Guido et al., 2001; Tripathi et al., 2006). Recently, Wong et al. (2010) also confirmed that the microbial biomass is generally negatively correlated with the concentration of soluble salts and positively correlated with SOC contents in coastal saline soils. However, some authors have reported that microbial activity and biomass were not affected by soil salinity or high pH (Sarig and Steinberger 1994; Beltrán-Hernández et al., 1999; Luna-Guido et al., 2000). These contradictory observations might be due to differences in quality of the added organic amendments or differences in the soil properties, especially the levels of salinity, specific ion species, water content, texture and organic matter level (Li et al., 2006; Muhammad et al., 2008).

Soil salinization is a major obstacle to sustainable agriculture in Hetao irrigation area of Inner Mongolia, China, and it affects 394,000 ha or 68.65% of the total arable land of the area (Lei et al., 2001). High evaporation rate, limited rainfall and shallow groundwater table contribute to the increase in soil salinity. It was reported that most of the saline soils in the area will eventually become totally unproductive and possibly abandoned if the salinity problem could not be resolved very soon and effectively too (Wu et al., 2008). Currently, plastic film mulching is widely used to reduce salt damage during seedling establishment and yield in this area. However, plastic film mulching has shown negative impact on SOC due to the increase in soil moisture and temperature (Li et al., 2004). Recently, in a three-year field trial (2011–2013), we showed that burying maize straw layer at a depth of 40 cm plus plastic mulching reduced evaporation from phreatic water, increased soil moisture (especially at the seedling stage), reduced soil salinity, and hence achieved a significant improvement in crop yield (Zhao et al., 2016). Moreover, the microflora diversity in salinized soil was significantly increased as a result of suitable micro-ecological environment under such management (Li et al., 2016). However, how this combined measures affect soil C pool in the arid salt-stressed soil has not yet been examined.

Soil organic carbon is of great importance in maintaining the pool of soil nutrients and improving nutrient availability (Lal, 2004). The loss of SOC may reduce soil fertility (Jamalam et al., 1998). Microbial biomass C (MBC) is an important fraction of SOC, and it is a general indicator of soil microbial activity (Wick et al., 1998; Gary et al., 2004). The dissolved organic C (DOC) is an energy source readily metabolized by soil microorganisms and affected directly by soil management (McGill et al., 1986). Soil organic carbon, MBC and DOC are frequently used to assess the influence of agricultural management practices on soil quality (Bremer et al., 1994; Gregorich et al., 1994; Dong et al., 2009). However, little is yet known of how the incorporation of maize straw layer combined with plastic film mulching affects SOC and its active fractions in arid saline soils. The overall objectives of this study were to: (1) assess the impact of burying straw layer plus plastic mulching on SOC, MBC, DOC, and (2) determine the correlations among SOC, MBC, DOC, soil temperature, moisture and salt concentration.

2. Materials and methods

2.1. Experimental site

Field experiments were carried out from October 2010 to September 2014 at the experimental station of the Yichang Irrigation Management Sub-district in Wuyuan County (41°04′N, 108°00′E, 1022 m ASL), Inner Mongolia, China.

The study area has a typical arid continental climate that is very cold in winter with little snowfall and very dry in summer with little rainfall. Local climatic characteristics have been described in our previous report (Zhao et al., 2016). The groundwater table varied from 1.2 to 2.6 m, with a salt concentration of 1.5–1.8 g L^{-1}. The experimental soil was silty loam with a pH of 8.8 and contained 11.1 g kg^{-1} organic matter, 35.6 mg kg^{-1} available N, 6.4 mg kg^{-1} available P and 161 mg kg^{-1} available K at the 0–10 cm layer.

The total precipitation during the experimental period was 64.8 mm in 2013 (2 June–30 September) and 103.5 mm in 2014 (8 June–3 October), accounting for 59.0% and 61.0% of annual precipitation respectively. The total pan evaporation was 1238.2 mm in 2013 and 1458.6 mm in 2014. The first season was drier than average (145.2 mm) for the corresponding period of the previous 10 years, whereas the second season was typical of the area.

2.2. Treatments and experimental design

The experiment had four treatments: (i) deep ploughing with no plastic mulching (CK); (ii) deep ploughing with plastic film mulching (PM); (iii) buried straw layer at a depth of 40 cm with no mulching (SL), and (iv) buried straw layer at a depth of 40 cm plus plastic film mulching (PM + SL). The treatments were arranged into a randomised complete block design with three replications. Each plot measured 4 m^2 (2 m × 2 m), and was insulated by double-plastic sheets buried to a 100 cm depth relative to the soil surface to minimise the effects of lateral water and salt movement between plots. Each plot was surrounded by a concrete panel 40 cm wide and 60 cm high, and the exposed part of panel (approximately 20 cm) was hardened with cement. The upper 40 cm of soil in the SL and PM + SL plots was removed at intervals of 20 cm depth and placed in different positions before uniformly placing the (air-dried) chopped maize straw to a thickness of about 5 cm (equal to 12 t ha^{-1}). The dug soil was refilled layer-by-layer and then flattened with a harrow to a bulk density consistent with the initial value. Plots were flood-irrigated in late October at approximately 0.6 m^3 per plot. To leach soluble salts for sunflower (*Helianthus annuus* L.) germination in each growing season, a second irrigation (0.6 m^3 $plot^{-1}$) was applied approximately 10 d before sowing. The straw layer burying operation was done once at the beginning of the experiment.

At sowing, the plots were ploughed to a depth of 15–20 cm and manually harrowed to a physically acceptable mellowness. According to local fertilizer practice, a compound fertilizer was applied at 180 kg ha^{-1} N (using urea, 46% N), 120 kg ha^{-1} P_2O_5 (using diammonium phosphate, 18% N and 46% P_2O_5) and 75 kg ha^{-1} K (using potassium sulphate, 50% K_2O). After fertilizer application, the soil surface was leveled.

Sunflower (cultivar LD 5009) was seeded at a row spacing of 60 cm and density of 49,000 plants per hectare. Seeding was manually done on 2 June 2013 and 8 June 2014; the crop was harvested on 30 September in 2013 and 3 October in 2014. After harvest and removal of sunflower stalks, flood irrigation was done using the same pre-sowing water volume per plot. Other management practices were performed according to local agronomic practices.