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Plastic film mulching improved rhizosphere microbes and yield of rainfed spring wheat

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ABSTRACT

Background and aims: Plastic film mulching (PFM) is critical for agricultural production in arid and semi-arid areas in the world. There is an evidence that PFM alters soil microbial populations and soil nutrients. However, how PFM altering rhizosphere microorganisms and nutrients with plant growth remain unknown. We investigated the changes of rhizosphere soil microbial metabolic characteristics in response to PFM management, and its consequent effects on soil nutrients, plant growth and yield of wheat.

Methods: A field experiment of a local spring wheat cultivar Lunchun 8275 was carried out at a typical semi-arid area on the Loess Plateau. Wheat plants were treated with or without PFM, and measured for rhizosphere cultural microbial populations and microbial metabolic activities at jointing, flowering and maturity stages, respectively.

Results: Rhizosphere cultural microbial populations and nutrient contents were significantly altered possibly due to the improvement of soil thermal and water status under the PFM treatment. The results of cultural microbial populations were consistent with the principal components analysis of microbial metabolic activities. PFM changed the linear regression coefficients between cultural microbial populations and nutrients, microbial metabolic activities and nutrients with 0.67 and 0.20 respectively, but with −0.24 and −0.37 in CK. Meanwhile, wheat grain yield increased by 19.2% and water use efficiency enhanced by 40.7% under PFM.

Conclusions: This study demonstrated that PFM improved rhizosphere micro-environment, including soil thermal and water status, rhizosphere nutrients, cultural microbial populations and their metabolic activities, thereby increased crop yield. The present study might enhance our understanding the influence of PFM on the rhizosphere microbes and their roles in nutrient acquisition and plant growth improvement.

1. Introduction

Mulches of straw and plastic film have been used to increase crop yield in north China (Li et al., 1999; Wu et al., 2009; Cui et al., 2015). Straw mulch is not recommended for application in the semiarid farmland on the Loess Plateau in Northwest of China due to the dramatically changes in day and night temperature. Plastic film mulching (PFM) technique has been adopted to solve this problem, and widely used to increase crop yield (Wang et al., 2017; Zhu et al., 2017). PFM inhibits soil water evaporation and raises topsoil temperature. And the changes of moisture and temperature also modify soil micro-environment, such as microorganism community, soil organic matter and nutrients etc., which may contribute to improving crop yield (Li et al., 2004; Liu et al., 2012; Wang et al., 2016; Zhang et al., 2017). Previous studies demonstrated that short-term PFM enhanced microbial biomass and nutrients cycling (Li et al., 2004), statistically changed AM fungi community compositions but not AM fungal phylotype richness (Liu et al., 2012), and significantly affected soil enzymes activity but not total aerobic counts (Wu et al., 2009). However, little is known about the effects of PFM on rhizosphere nutrients, cultural microbial populations and their metabolic activities, and their contributions to crop growth and yield.

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Rhizosphere micro-environments, such as microbial communities, soil water and thermal status, the availability of soil nutrients etc., are the most important factors to limit plant growth and productivity (Prosser et al., 2007; Miransari, 2013). Soil microbes play a key role in agro-ecosystems, by directly and indirectly participating in soil nutrients and energy cycling to improve plant growth and yield (Falkowski et al., 2008; Herzberger et al., 2014; Zhu et al., 2017). In most cases, soil nutrients are in chelates or combination states, which cannot be used directly by plant. But soil microbes have the capability to transform invalid nutrients to effective nutrients (Lu et al., 2015; Cui et al., 2015). Moreover, soil microbes vary with soil types and agronomic measurements (Sul et al., 2013). Previous studies showed that PFM increased soil microbes, eg. arbuscular mycorrhiza fungi community compositions in wheat field (Liu et al., 2012) and soil bacterial community in orchard soil (Cui et al., 2015). But these studies often lag behind the changes in land use and land management (Kulmatiski and Beard, 2008; Fichtner et al., 2014).

In order to understand how soil microbial communities changed in response to land management of PFM, and to determine the relationship among rhizosphere nutrients, cultural microbial populations, microbes metabolic activities and crop growth and yield, a field experiment of spring wheat was established with treatments of soil mulched with or without plastic film. We hypothesized that PFM practice (1) influenced cultural microbial populations, microbes metabolic activities, soil nutrients and plant growth at different growth stages, (2) altered the relationship between nutrients cycling and soil microbial function diversity, and (3) eventually improved wheat growth performance and yield.

2. Materials and methods

2.1. Field description and sample collection

The field site was located at the Institute of Biology Experimental Station, Heping Town, Lanzhou City, Gansu Province, China (38°39′N, 104°4′E, altitude 1517 m), which represents a typical cold temperate and arid climate in northwest China, with the annual average rainfall of less than 400 mm and annual temperature of 7 °C. The soil is classified as Aridosol (Zhou and Shen, 2013). Plastic film mulching is an efficient farming technology to improve agricultural provision in this area. Spring wheat is one of the main crops in this area and was chosen as test material.

Eight 1.5 m × 1.2 m plots were established in the spring of 2014, consisting of two mulching treatments, namely with or without plastic film mulched (PFM or CK) with four replicates. Before tillage, basal fertilizers including urea (600 kg hm^{-2}), tricalcium phosphate (368 kg hm^{-2}), and organic fertilize were manually broadcasted into each plot, and mixed into the soil using a rotary tillage machine. For the PFM treatment, 1.5 m plastic film was used to cover the soil surface with the edges buried with soils. There was 0.5 m buffer strip between the neighbouring plots. Seeds of spring wheat (*Triticum aestivum* L. c.v. Lunchun 8275) were sown by hand with 266 plants according to local bunch planting density.

Wheat plant growth and rhizosphere soils were sampled at three different growth stages (Zadoks, 1985): (1) jointing (Zadoks code 30), (2) flowering (Zadoks code 69), and (3) mature stages (Zadoks code 94). Six plants were randomly sampled in each plot and rhizosphere soils of each plant were taken using a corer (10 cm diameter, and 25 cm depth). Plant above ground parts were separated from the roots and taken to the lab for further analysis. We collected the rhizosphere soils from the below-ground parts. Firstly, rhizoplane soils were generally removed by shaking the root system. The root system with some soil attached was put into an aseptic ziplock bag. And then gently rubbed the root system over the bag by hand to collect rhizosphere soil by separating from the roots. After removing root segments, rhizosphere soils were mixed together for the same treatment and divided into three subsamples. Subsamples were stored in sealed bags in an icebox for transporting to a lab for cultural microbial populations, Biolog plate and nutrients analysis, respectively.

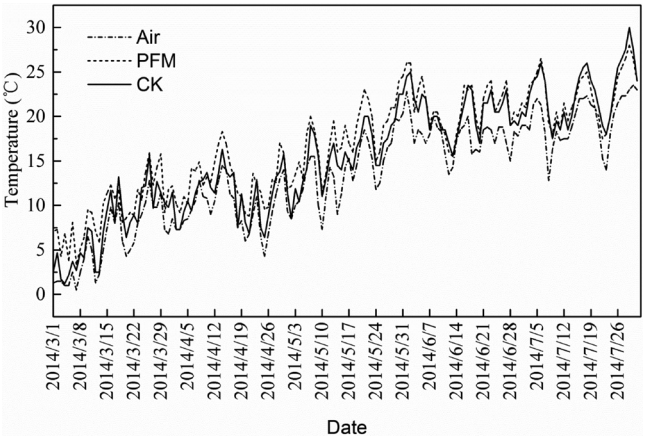

Fig. 1. Dynamics of daily soil temperature at 10 cm soil depth under the PFM and CK treatments during wheat growth stage.

2.2. Soil temperature and water storage

Air and soil temperature at 10 cm soil depth, was monitored hourly by thermometer loggers, and the day mean temperature was calculated from twenty-four temperature data. Soil temperature changed dramatically with air temperature, and soil temperature under PFM treatment were higher than that of CK during wheat growth season (Fig. 1).

Soil water storage (SWS) was calculated from soil water content (SWC) by the formula: $SWS = SWC \times \rho b \times H$. *SWC (%)* was measured by gravimetrical method for the upper 1000 mm of the soil at intervals of 100 mm at jointing, flowering and maturity stages. ρb is the soil bulk density (g cm^{-3}), the value is 1.26 g cm^{-3} and H is the soil depth (mm).

2.3. Measurements

Above ground biomasses were estimated based on 24 − plant sampled at three growing stages after dried at 105 °C for 30 min, and then at 60 °C for 48 h. The remainder of wheat plants were harvested at maturity, sun-dried and calculated production. Water use efficiency was calculated for above-ground biomass and grain yield, respectively:

$$WUE_Y = Y/ET \text{ and } WUE_B = B/ET$$

where Y is the grain yield (g m^{-2}), B is the above-ground biomass (g m^{-2}), and ET is the evapotranspiration (mm) during growing season and is calculated by the following formula:

$$ET = P + \Delta W$$

where P is the total growing-season precipitation (mm), and ΔW is the difference in SWS between sowing and harvest over the upper1000 mm of the soil profile (Zhu et al., 2017).

Soil organic matter (SOM) was analyzed by the dichromate oxidation method by digesting the samples with 0.8 mol L^{-1} 1/6 $K_2Cr_2O_7$ and 98% concentrated H_2SO_4 at 150 °C for 45 min, and then measured by titration with 0.2 mol L^{-1} $FeSO_4$ (Wu and Chen, 2016). Total nitrogen (Total N) concentrations were analyzed using the Automatic Kjeldahl analyzer (A1225 Automatic Kjeldahl analyzer, Thmorgan, Germany). Soil samples were first digested with 98% concentrated H_2SO_4 and catalyst at 400 °C for 100 min, and the total N concentration was determined by Automatic Kjeldahl analyzer after cooling (Zhang et al., 2015).

Available phosphorus (available P) was determined by ultraviolet spectrophotometry. Soil samples were extracted with sodium