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Changes in soil enzymes, soil properties, and maize crop productivity under wheat straw mulching in Guanzhong, China

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A R T I C L E I N F O

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A B S T R A C T

Addition of organic material, such as crop straw mulch in most soils is considered a strategy for sustainable agricultural production. We conducted a two-year experiment in 2015 and 2016 to determine changes in soil biochemical properties and maize yield in response to treatment with wheat-straw mulch. The treatments consisted of the addition of different levels of wheat-straw mulch (S1: 0, S2: 2500, S3: 5000 kg ha^{-1}). Soil samples from four depths (0.1, 0.2, 0.3, and 0.4 m) were collected and analyzed. Soil enzymes, such as invertase, phosphatase, urease, and catalase, were significantly higher in the S3 treatment than in the S1 treatment. Values were greater for the samples collected at 0.1 m soil depth than those collected from deeper soil layers. Regarding soil properties, soil organic carbon (SOC), available nitrogen (AN), available phosphorus (AP), total nitrogen (TN), total phosphorus (TP), and soil water content (SWC) were significantly higher in S3 at 0–0.1 m soil depth than in other treatments. Compared with the (S1), an average increase in SOC, AN, AP, TN, TP, and SWC in 0–0.4 m soil depth with full straw mulch (S3), were 32.4, 31.9, 32.0, 11.8, 16.7, and 18.5%, higher, respectively. On average, urease, phosphatase, invertase, and catalase increased by 15.1, 11.0, 88.4, and 24.0%, respectively in the S3 treatment compared with that in the S1 treatment at 0–0.1 m depth, and decreased with increasing soil depth. The S3 treatment had increased grain yield (7%), biomass yield (28%), and water use efficiency (8%), compared with the S1 treatment. Overall, our results suggested that the S3 straw mulch treatment (5000 kg ha^{-1}) could be used to sustain maize productivity and promote a better relationship between soil enzymes and soil properties in the semi-arid conditions of the Guanzhong area.

1. Introduction

The improper and excessive use of inorganic fertilizers degrades soil health (Wolf, 2006). Use of excess N fertilizer at concentration of approximately 300–400 kg N ha^{-1} to produce high high-grain yields in wheat and maize crop systems, has been associated with a decline in soil organic matter (Cui et al., 2008; Ju et al., 2009). Several studies have documented that burning or removing crop residues caused significant losses to soil organic matter and associated nutrients (Mendham et al., 2003; Prieto-Fernández et al., 2004). The *in situ* retention of harvest residues is an alternative management practice to control such losses (Blumfield and Xu, 2003). Thus, we hypothesized that application of wheat-straw mulch would improve nutrient cycling, coupled with improvement in soil enzyme activity and maize productivity in semi-arid regions of China.

Mulch can be classified into two main groups, organic and inorganic. Organic mulches include crop straw, pine needles, and wood chips (Thurston, 1997). Mulch protects the soil from biotic and abiotic stresses and improves soil health (Wade and Sanchez, 1983). The decomposition rate of organic mulches depends on the type of mulch material. Mulches can (i) control runoff and soil erosion, (ii) decrease soil temperature and evaporation thus decreasing soil water losses, (iii) provide a favorable environment for soil enzymes, and (iv)improve soil productivity (Mando and Stroosnijder, 1999; Naeini and Cook, 2000a; Naeini and Cook, 2000b).

Crop residues are used as a source of organic matter and nutrients in soil and also are used as feed for livestock. Recently, additional interest has arisen for their use as biofuels and in industrial fiber production (Gomez et al., 2008). Crop straw is a source of carbon, and the addition of crop straw was shown to result in better accumulation of soil organic carbon (Bakht et al., 2009). However, researchers are still not sure that straw removal has significant effects on soil quality and nutrients

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cycling (Wilhelm et al., 2007). Wilts et al. (2004) reported that straw has a direct linear relationship with soil carbon and SOM. However, Lafond et al. (2009) reported that straw mulch had no significant effects on soil quality or crop production. The crop system and climatic zone are responsible for straw harvesting. The use of harvest-straw mulch can reduce evaporation, and therefore increase soil moisture content and enhance maize growth and development, increasing grain yield and water use efficiency (WUE) (He et al., 2009; Tao et al., 2013). Straw mulching is a traditional cultivation method used to improve crop yields, especially in arid areas (Hou et al., 2012; Verhulst et al., 2011). Normally, straw mulching is expected to reduce the temperature at soil depth of 0–0.1 m, to reduce evaporation, and to increase dry matter accumulation during the growing period (Sharratt et al., 1998).

Changes in soil fertility depend on the changes in soil enzymes or in soil degradation, which can also be useful in sustainable management of soil quality and environmental stability (Monreal et al., 1998). Among all soil variables, only enzymes react quickly to changes in soil management, and therefore may be a good indicator of soil biological change (Bandick and Dick, 1999). In the cycling of nutrients, some hydrolytic enzymes are involved (β-glucosidase, urease, and phosphatase linked to C, N, and P). These enzymes are sensitive indicators to changes in soil properties and show a strong relationship with SOM contents and quality (Caravaca et al., 2002).

Previous studies documented that significant losses of SOM and related nutrients were caused by burning of harvested residues (Mendham et al., 2003; Prieto-Fernández et al., 2004). The management of residues can affect microbial processes, which are involved in soil carbon and nutrient transformations (Mendham et al., 2003) and enzymatic activity controlling the availability of the most limiting nutrients for microbial metabolic demands (Jin et al., 2009). The objective of the experiment was to determine the effects of different straw mulching rates on soil nutrients, soil enzyme activity levels and maize crop productivity in Guanzhong, in order to serve as a reference for agricultural residue management in semiarid regions.

2. Materials and methods

2.1. Site description and experimental design

The experimental site (34°12′N and 108°07′E) is situated within Northwest A & F University, China, Yangling, Shaanxi Province. The area is 520 m above sea level. Mean annual temperature and precipitation are 12.9 °C and 660 mm, respectively, and precipitation is mainly concentrated from July to September. The soil is classified as Lou soil, and the texture of soil is silt clay loam. The physical and chemical properties of the initial soil (0.1 m) in 2011 were as follows: pH 8.3, bulk density 1.53 g cm^{-3}, saturated soil water content 44%, field capacity 22.4%, EC 170 μS cm^{-1}, soil organic C (11.2 g kg^{-1}), available N (26.5 mg kg^{-1}), available P (5.1 mg kg^{-1}), exchangeable K (132 mg kg^{-1}), total N (0.52 g kg^{-1}), total P (0.49 g kg^{-1}).After five years of these treatments imposition, field studies with the same treatments were re-designed in 2015 and 2016 to quantify soil enzyme activities, soil properties, and crop productivity in response to prolonged and immediate use of these treatments imposition in Northwest A & F University, Shaanxi Province, in a maize-wheat rotation system.

The experiment was designed in RCBD with three replications. Straw mulching was arranged in the main plot and soil depth in subplot, for soil enzymes and soil properties only. The data for each year was analyzed separately. The biomass, yield and water use efficiency data were analyzed according to the RCB design with year as repeated and fixed factor. The wheat-straw mulch treatments were S1: 0, S2: 2500 kg ha^{-1} and S3: 5000 kg ha^{-1} and occurred at four soil depths (0.1, 0.2, 0.3, and 0.4 m) in 2015 and 2016. The area of each plot was 66 m^2 (8.0 × 8.25 m) and soil samples were collected from three different places starting at a soil depth of 0.40 m and increasing at intervals of 0.1 m soil layers in each plot. During wheat harvest, the straw mulching

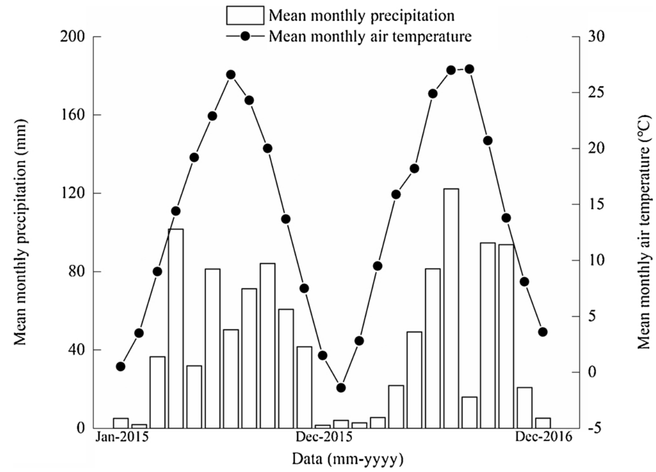

Fig. 1. Mean monthly precepitation and air temperature during 2015 and 2016.

treatments were maintained for the next maize crop in 2015 and 2016. Nitrogen fertilization as urea was applied equally to all plots at the rate of 172 kg ha^{-1} every year at the jointing stage. The summer maize (cultivar Luo dan No. 9) was planted at a seeding rate of 60 kg ha^{-1} on 15 June 2015, 17 June 2016, using a machine and depth controlling wheel at a row spacing of 0.75 m; 0.25 m of space was maintained between plants. Manual weeding was conducted as required during the field experiment each year. Irrigation of 120 mm was provided on the 10th and 18th of July in 2015 and 2016. The experimental field was not plowed before sowing of the maize crop. The precipitation and air temperature data is presented in Fig. 1.

2.2. Soil sampling and measurement

Soil samples were collected by a core sampler at different depths of 0.1, 0.2, 0.3, and 0.4 m from each plot immediately after maize harvest (i.e., before straw mulching) during September of each year. At five different points in each plot, five subsoil samples were collected and mixed by quartering them to make a composite sample. This sample was divided into two parts, one was used for soil nutrient analysis and the other was used for soil enzyme analysis and stored at 4 °C.

The oven-drying method was adopted for measuring soil water content. The soil samples from 0-0.4 m soil depth were collected using a soil auger, and every 0.1 m of soil was considered one soil sample. Three soil samples were taken from each plot and dried in an oven at a temperature of 105 °C and removed after 12 h.

The physical and chemical analysis methods of soils were used for the analysis of all soil nutrients (ISSCAS, 1978). Soil organic carbon was determined by the oxidation method with $K_2Cr_2O_7$-H_2SO_4 followed by titration with $FeSO_4$ (Wang et al., 2003).

Total soil nitrogen was analyzed using the Kjeldahl method with the Foss Kjeltec analyzer. Soil available nitrogen determination was performed by the method of Dorich and Nelson, (1984). For measurement of soil total phosphorus, soils were first digested by a mixed acid solution of H_2SO_4 and $HClO_4$, and then analyzed by the Mo-Sb colorimetric method. Soil available phosphorus was obtained by $NaHCO_3$ extraction, and then, analyzed by the Mo-Sb colorimetric method with a spectrophotometer (UV2550, Shimadzu, Japan) (Bao, 2000).

The determination of soil enzyme activities was performed as described by Zhang et al. (2011) and Jin et al. (2009). Activity of soil catalase was determined by the addition of 40 mL distilled water and 5 mL 0.3% H_2O_2 to 2 g fresh soil. The mixture was shaken for 20 min (at 150 rpm) and then filtered (Whatman 2 V) immediately and the filtrate was titrated with 0.1 mol L^{-1} $KMnO_4$ in sulfuric acid.

Soil invertase activity was determined using 8% glucose solution as the substrate. A 5 g fresh soil sample was incubated with 15 mL