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Research paper

Continuous plastic-film mulching increases soil aggregation but decreases soil pH in semiarid areas of China

Lin Wang, Xiao Gang Li*, Jieting Lv, Taotao Fu, Qiujin Ma, Wenyuan Song, Yong Peng Wang, Feng-Min Li

State Key Laboratory of Grassland and Agro-Ecosystems, Institute of Arid Agroecology, School of Life Sciences, Lanzhou University. 222 South Tianshui Road, Lanzhou 730000, China

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ABSTRACT

Plastic-film mulch is a globally applied agricultural practice. However, its effects on soil aggregation and pH have been hardly studied. We assessed the effects of plastic-film mulch on soil aggregate water-stability and pH in fields used for maize (*Zea mays* L.) production, at two sites in a cold semiarid environment, China. Four treatments were used: (i) no plastic-film mulch and no straw incorporation, (ii) plastic-film mulch only, (iii) straw incorporation only, and (iv) straw incorporation plus mulch. Seven years after continuous treatment application, the use of plastic-film mulch increased the proportion of water-stable macroaggregates (>0.25 mm) in the top 15-cm soil layer by 16–28%, across sampling times and sites. Straw incorporation similarly increased the proportion of water-stable macroaggregates. However, the effects of mulch, on increasing the mean weight diameter of aggregates were greater in non-straw-incorporated soils than in straw-incorporated soils, and vice versa. Soil bulk density in the top 15-cm soil layer marginally increased in the mulched treatments, relative to the non-mulched treatments, while it decreased in straw-incorporated treatments. In addition, there was a decrease in soil pH, by 0.19–0.54 units, in the mulched, relative to the non-mulched soils. Combining our previous results, we suggested that increases in maize root growth and microbial activity were linked to the increased soil aggregation while accumulation in soil nitrate resulting from the stimulated soil nitrogen mineralization was responsible for the marginally decreased soil pH in the plastic-film mulched relative to the non-mulched soils, due to increased soil hydrothermal conditions.

1. Introduction

Soil aggregates and their stability play a vital role in regulating other soil properties (Tisdall and Oades, 1982; Bronick and Lal, 2005; Chen et al., 2014). Soil aggregates determine the soil pore network and thus are linked to root stretching, water infiltration and retention, aeration and the thermal regime in the soil profile. Soil aggregates have a major influence on soil organic carbon (SOC) and nutrient cycling, and the diffusion of nutrients and solutes through the soil. Therefore, soil aggregates and their associated structural properties, affect the establishment, growth, nutrient and water uptake, and ultimately the productivity of crops (Pardo et al., 2000; Atkinson et al., 2009; Fuentes et al., 2009). In addition, the size and stability of soil aggregates determines soil erodibility (López et al., 2000; Planchon et al., 2000; Somaratne and Smettem, 1993; Ghosh et al., 2016). Soil pH is one of most important soil chemical attributes. It influences plant growth directly, through regulating physiological activities in seed germination and root growth, and indirectly, through its effects on ion mobility, precipitation and dissolution equilibrium, microbial activity and nutrient availability of soil (Bloom, 2000).

While both soil aggregation and pH affect plant growth, they are also influenced by cultivation intensity (Adem et al., 1984; Guo et al., 2010; Minasny et al., 2016). Plastic-film mulching has become a globally applied agricultural practice (Steinmetz et al., 2016). In China, a technique using plastic-film mulch in a ridge–furrow configuration was recently proven effective for increasing crop productivity. Therefore, it has been extensively used for maize (*Zea mays* L.) production in semiarid areas of China (Gan et al., 2013). Under this system, soil water evaporation is reduced and soil temperature is increased, because the whole soil surface is covered with clear plastic film. Precipitation on the covered ridges is channeled into the furrows (where the crop is sown) and infiltrates

* Corresponding author at: School of Life Sciences, Lanzho University, 222 South Tianshui Road, Lanzhou, 730000, China.
E-mail addresses: lixg2002@hotmail.com, lixiaogang@lzu.edu.cn (X.G. Li).

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the root zone through perforations in the plastic-covered furrow (Jiang and Li, 2015). The improved soil hydrothermal conditions stimulate soil microbial activity and thus accelerate carbon and nitrogen transformation (Zhang et al., 2012; Liu et al., 2014; Wang et al., 2014, 2016c; Hai et al., 2015). In combination, the improved soil hydrothermal conditions and nutrient availability comprise the basic mechanisms for the increase in plant productivity under plastic-film mulched ridge–furrow cropping. However, besides environmental concerns from plastic residues (da Costa et al., 2016; Steinmetz et al., 2016; Wang et al., 2016a), whether this highly-intensified cropping system changes the soil's structural and chemical properties has been rarely studied.

High plant productivity using plastic-film mulch should not be achieved at the expense of the long-term degradation of soil resources (Steinmetz et al., 2016). A better understanding of the interaction between the soil microclimatic and biological changes on soil physiochemical properties under plastic mulching practices is crucial for estimating the potential changes to soil quality. The present study is part of a larger experiment which assessed the effects of plastic-film mulch on maize productivity and soil quality along a hydrothermal gradient. The major parts of the research (variation in productivity and SOC balance in croplands) had been published (Wang et al., 2016b,c). We showed that the continuous use of plastic-film mulch significantly increased the maize grain yield by 30–107% and aboveground biomass by 37–69% compared with non-mulched plots across five semiarid sites, due to increasing soil temperature and moisture principally during early growth (Wang et al., 2016b). The increase in soil temperature and moisture by use of plastic-film mulch enhances productivity, while maintains the SOC level in temperature- and rainfall-limited semiarid regions by balancing the increased SOC mineralization with increased root-derived carbon input (Wang et al., 2016c). The objective of the present study was to examine the effect of the continuous plastic-film mulch on soil aggregation and pH. We hypothesized that plastic-film mulch cropping would increase both soil aggregation and the stability of aggregates. This is because plastic-film mulch significantly increases root growth and soil microbial activity (Liu et al., 2014; Wang et al., 2016c); these are known factors facilitating soil agglomeration (Tisdall and Oades, 1982). In addition, we hypothesized that plastic-film mulch cropping would decrease soil pH, because it increases soil nitrogen availability during plant growth and the levels of nitrate residues in the soil after crop harvest (Wang et al., 2005, 2014, 2015b; Gao et al., 2009).

2. Materials and methods

2.1. Sites and experimental design

The same experimental design was implemented continuously in a field at each of five sites in Gansu Province, China: Ningxian, Chongxin, Tongwei, Huining and Yuzhong (Wang et al., 2016b,c). Measurements of soil aggregation and pH of the present study were only incorporated into the treated plots at Huining (35°32′N, 105°04′E; 1810 m a.s.l.) and Yuzhong (35°54′N; 104°05′E, 2013 m a.s.l.) of those five sites. Mean annual rainfall and mean temperature (1982–2012) were 410 mm and 7.1 °C at Huining, and 388 mm and 6.7 °C at Yuzhong, respectively. The soils at the two sites were classified as Entisols, developed from wind-blown loess. According to the second national soil survey, the soils in both areas contained (on average) 131 g kg^{-1} carbonates (as $CaCO_3$), with a mean exchangeable cation content of 89 mmol (+) kg^{-1} (Gansu Province Soil Survey Office, unpublished report). Each site consisted of a flat field that had been cropped for many years. The soils of the two fields had a silt loam texture (2–0.05 mm 5.5–6.7%; 0.05–0.002 mm 71.1–72.5%; <0.002 mm 22.0–22.1%). At maize (*Zea mays* L.) sowing in 2009, the soil bulk density in the top 15-cm soil layer was 1.00 and 1.08 g cm^{-3}, with pH values (water:soil = 2.5:1) of 8.1 and 8.0 at Huining and Yuzhong, respectively. The total SOC and total nitrogen levels were 9.29 and 1.03 g kg^{-1} at Huining and 12.0 and 1.24 g kg^{-1} at Yuzhong. The soils had mineral nitrogen and Olsen phosphorus concentrations of 82 and 56 mg kg^{-1} at Huining and 84 and 36 mg kg^{-1} at Yuzhong, respectively.

A detailed description of the experimental design had been given by Wang et al. (2016b,c). At each site, four treatments with three replicates of each were implemented in the ridge–furrow fields: (i) control (no plastic-film mulch and no straw incorporation); (ii) plastic-film mulch only; (iii) straw incorporation only; and (iv) plastic-film mulch with straw incorporation. The 12 plots (4 treatments × 3 replicates) were each 41.8 m^2 at Huining and 39.6 m^2 at Yuzhong. The experiment was started in October 2008 and the treatments were repeated for each cropping season in one field up to October 2015. For the straw incorporation treatment plots, maize straw (stems and leaves, <0.06 m in length) was applied in late October each year. The amount of maize straw incorporated was between 5 and 7.5 t ha^{-1} (constant mass at 60 °C; containing 439 g carbon and 6.7 g nitrogen kg^{-1}; carbon/nitrogen = 65.5). Urea, at 276 kg nitrogen ha^{-1}, and superphosphate, at 37 kg soluble phosphorus ha^{-1}, were spread on each plot before plowing to a depth of 15 cm with a spade. This fertilization scheme was recommended by the Gansu Province Agricultural Service department. Then, alternate narrow (15 cm high × 40 cm wide) and wide (10 cm high × 70 cm wide) ridges were established in all treatments.

For the plastic-film mulch treatments, the entire soil surface was covered with colorless, transparent, 0.008 mm thick polyethylene film. After covering the soil with the plastic film, holes (1.5 cm diameter, 20 cm apart) were punched through the film in the furrows. These holes and those made at sowing allowed rainwater from the ridges to enter the soil in the furrows (Liu et al., 2014; Jiang and Li, 2015). The plastic-film mulch ridge–furrow system was prepared before winter, rather than in spring, to conserve more rainwater in the soil, by blocking soil evaporation over the winter (Liu et al., 2009); this is widely practiced in the areas.

In the following late-April, each year, 12 rows of maize were hand sown in each plot after punching new holes in the furrows. The sowing density was about 52,500 plants ha^{-1}. The maize cultivars used at each site were those commonly grown locally (Wang et al., 2016b). After harvest each year, straw was removed from every plot, chopped with a hay chopper and then used for the next-season's straw incorporation treatment. After harvest, the ridges and furrows were re-established and the plastic-film replaced for the next year (Wang et al., 2016b).

2.2. Sampling and analysis

Maize yield and biomasses, soil temperature and moisture and SOC concentration and composition had been all measured using standard methods at each of five sites, and results up to the cropping year of 2014 had been published by Wang et al. (2016b,c). In the present study at Huining and Yuzhong, the maize grain yield and root biomass and total SOC concentration at harvest in 2015 were also measured using the same methods as in the previous years. The maize grain yield and root biomass averaged over the period from 2009 to 2015 were presented in Table 1 to give a background of the present study. The SOC concentration in the top 15 cm layer measured at harvest in 2015 was also shown in Table 1.

At the maize peak growth (July) and harvest (October) time in 2015, soil samples were randomly collected using PVC tubes (75 mm inner diameter; 150 mm height) from 6 narrow ridges within each plot at two sites of Huining and Yuzhong and used for