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Effects of plastic mulch and crop rotation on soil physical properties in rain-fed vegetable production in the mid-Yunnan plateau, China

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ABSTRACT

Plastic mulch is widely used for vegetable cropping in the mid-Yunnan plateau, southwestern China. However, the effects of plastic mulch on soil physical properties are poorly understood. A field experiment was conducted to evaluate the effects of different plastic mulch patterns (narrow and wide plastic mulch) and rotations (broccoli–zucchini–winter wheat and broccoli–zucchini–fallow) on soil physical properties and soil organic carbon content in a vegetable production system at a research station in the region. The experiment comprised four treatments and laid out in the field using randomized complete block design replicated nine times. The soil (0–20 cm) under wide plastic mulch retained more water than the soil narrow plastic mulch under the vegetable growing season over 3 consecutive severe drought years. Significant decline (11%) of surface soil (0–5 cm) organic carbon was observed in 2012 compared with in 2010, but soil organic carbon and physical properties did not differ significantly between the two different plastic mulch patterns. The higher macro-porosity, aggregate stability, K_{sat} and lower bulk density in the plastic mulched ridges imply that the conversion from narrow-plastic-mulch to wide-plastic-mulch increases mulched area thereby conserving larger area soil structure in the croplands. Although increased catch crop stubble retention in the furrows apparently improved surface soil macro-porosity and saturated hydraulic conductivity, the autumn rotary cultivation in broccoli–zucchini–winter wheat rotation system has significantly decreased (5%) surface soil organic carbon. The results suggested that continued use of vegetable–cereal crop rotation system, even with stubble retention, may result in loss soil organic carbon. Further research that covers wetter years should be taken to assess effects of vegetable–cereal crop rotation pattern on soil physical properties in this region.

1. Introduction

Soil degradation is a major environmental problem worldwide which present an immediate and long-term hazard to crop yields. Intensive farming practices have been considered the most degradative system of land use (Wan and El-Swaify, 1999). The main consequences of long-term intensive farming practices are the degradation of soil structure and loss of soil organic matter (SOM). Much of the environmental damages in intensive arable lands such as nutrient deficiency, erosion and susceptibility to compaction originate from SOM decline and soil structural degradation. Therefore, it is important to maintain proper levels of SOM and soil structural stability to sustain soil productivity in arable lands.

In vegetable production systems, plastic mulch has been used as the preferred intensive cultivation method for most crops because it controls weeds, warms the soil, and prevents soil from depositing on the crops (Fisher, 1995). Mulched plants commonly show significant increases in yield and fruit quality. However, Liu et al. (2013) reported that plastic mulch in ridge and furrow systems has challenges in maintaining soil fertility due to exhaustion risk of soil organic carbon (SOC) and soil nitrogen. The decline in SOC results in a deterioration of soil physical conditions, leading to unsustainable crop production (Greer et al., 1996).

Vegetable cropping has been prosperous at the mid-Yunnan plateau for two decades. Under ridge-and-furrow systems, various vegetables such as cabbage, broccoli and zucchini have been intensively cultivated in plastic-mulched fields. To maximize profits, an increasing area of upland soil has been used for vegetable production by local farmers where the greatest amount of soil erosion occurs. Because precipitation is the major water resource for crop production in the upland, the local farmers conventionally cultivate vegetable crops in the wet season (from June to November) and cereal crops in the dry season (from December to May). After cereal crop harvest, local farmers usually

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move away residues to avoid impacting next vegetable crops growth. The field is tilled in May and November every year for vegetable and cereal crop respectively. In recent years, because of the high variability of rainfall in mid-Yunnan plateau, progressively more local farmers have used 2.0 m wide plastic film instead of the conventional 0.9 m wide plastic film to decrease soil moisture evaporation in crop bed. This practice obviously increases the impervious surface area thereby could result in severe runoff in the vegetable crop fields. Moreover, many crop fields are fallowed by local farmers in the dry season to sustain more soil moisture for the next vegetable crop. A critical question is to what extent the new farming practice contributes to soil physical quality as compared to traditional practices.

Because sustainable vegetable production systems depend increasingly on soil physical conditions in the hilly area of the mid-Yunnan plateau, it is necessary to evaluate the effects of management practices on stability of soil structure and accumulation of SOC in the region. The objective of this work is to identify effects of different plastic mulch patterns and rotations on soil physical properties and soil organic carbon content. We hypothesized that plastic mulch would protect soil structure but reduce soil organic carbon, and that under vegetable–cereal crop rotation, stubble retention would result in the accumulation of soil organic carbon.

2. Materials and methods

2.1. Site description and experimental design

A plastic mulching/rotation experiment was established in early summer 2010 at the Shuangsuan Research Station of Yunnan University, located on the mid-Yunnan plateau of southwestern China, at an elevation of 1950 m (Latitude: 24°36′ N; Longitude: 102°41′ E). Mean annual rainfall in the area is 879 mm. Mean annual temperature is 14.7 °C. Both mean monthly temperature and rainfall follow a similar pattern usually peaking in July/August. Drought is usually restricted to spring when excess water from the previous summer is exhausted and evaporation is at a maximum. The soil at the site is a red earth (Soil Taxonomy: Ferric Acrisol, according to FAO, 1998) with pH 5.6, total C 12.14 g/kg, total N 1.50 g/kg. Soil particle size distribution of sand, silt and clay was 10%, 50% and 40%, respectively.

The experiment had a fully phased factorial design with two plastic mulch treatments (narrow vs. wide plastic mulch) and two rotation treatments (broccoli [*Brassica capitata* var. *italica*]–zucchini [*Cucurbita pepo* L.]–winter wheat [*Triticum aestivum* L.] vs. broccoli–zucchini–fallow), replicated nine times (Fig. 1). The previous crop prior to the experiment was sweet maize. There were 36 plots in total. The plot size was 10m × 4 m with mean slope angles of 3–5°. For the narrow-plastic-mulch treatment (NPM), plastic film was laid out in 0.9 m wide strips over the ridge and the edges were covered by soil. Broccoli was transplanted in a ridge in pair rows 50 cm apart in early June. Thus, each plot consisted of three 10.0-m-long by 0.8-m-wide ridges with 120 plants, and four 0.4-m-wide by 0.15-m-deep trapezoidal furrows. For the wide-plastic-mulch (WPM) treatment, plastic film was laid out in 2.0 m wide strips over the ridge and the edges were covered by soil, forming a furrow between two ridges. Broccoli was transplanted to the ridges in rows of three and spaced 50 cm apart in early June. This plot had 120 plants in two 10.0-m-long by 1.8-m-wide ridges, with a 0.4-m-wide by 0.15-m deep trapezoidal furrow. Comparing the two systems, the percentage of bare furrow area over the vegetable plot was much higher in the NPM (40%) than the WPM (10%).

In order to improve seedling growth, each broccoli plant was watered by hand with approximately half a liter of water after being transplanted. After the broccoli had been harvested at the end of August, zucchini seeds were sowed in the vacated holes in the plastic mulch beds. After the zucchini had been harvested at the end of October, the soil for the broccoli–zucchini–winter wheat (B–Z–W) treatment was rotary cultivated to a 0.15-m-depth and winter wheat was sowed at a rate of 250 seeds per m^2. All of the wheat straw on the B–Z–W treatment plots was incorporated into the soil by subsequent ridge and furrow systems rebuilding operations in late May before the broccoli transplant. For broccoli–zucchini–fallow (B–Z–F) treatment, after zucchini harvest, the plots were left fallowed with the plastic mulch remained intact until next late May when the ridge and furrow systems was rebuilt after rotary cultivation to 0.15-m-deep for broccoli transplant. In order to ensure a realistic simulation of the local agricultural management, regional practices of transplanting and sowing were used. Furthermore, the whole field received the same fertilizer applications of nitrogen and phosphorus. The chemical breakdown for the two crops was as follows: 420 kg N/ha and 80 kg P/ha (broccoli); 180 kg N/ha and 80 kg P/ha (zucchini). Fertilizer was not applied during the winter wheat growth period. No reduction in fertilizer inputs was made in the winter wheat residue retention treatments because of the nutrient inputs from stubble were very low (Zhang et al., 2013).

2.2. Measurements and soil sampling

2.2.1. Precipitation events and soil moisture

Daily precipitation data were collected by an autographic rainfall gauge installed in the middle of the experiment site. Soil

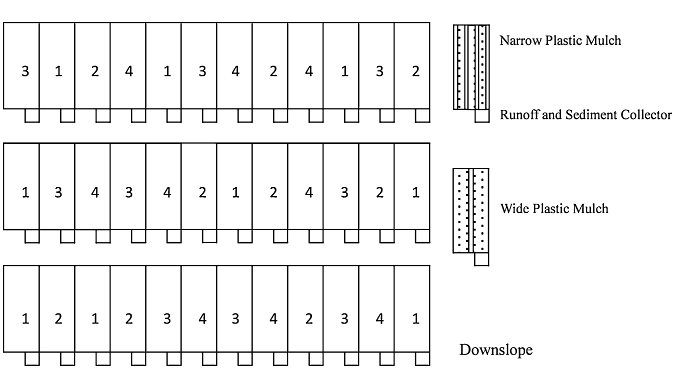

Fig. 1. Experimental layout of erosion plots at the Shuangsuan Research Station of Yunnan University.

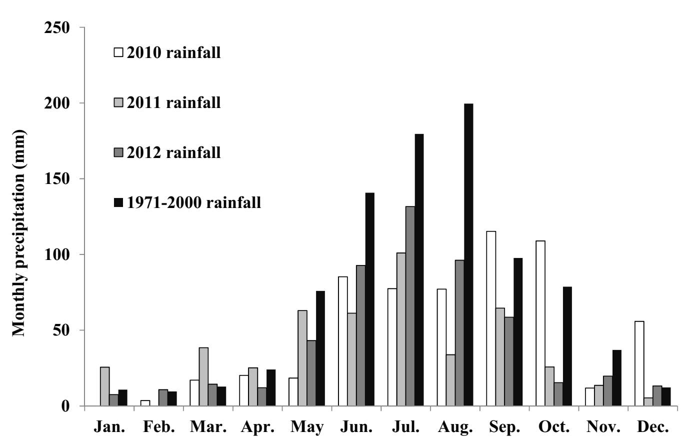

Fig. 2. Monthly precipitation for the experiment site in 2010–2012, and mean monthly rainfall for Jinning county during 1971–2000.