



Winter tillage impacts on soil organic carbon, aggregation and CO₂ emission in a rainfed vegetable cropping system of the mid-Yunnan plateau, China

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ABSTRACT

The mid-Yunnan plateau is one of the major regions for the production of vegetables in China, but intense management practices have led to soil degradation and amplified greenhouse-gas emissions. Understanding management effects on soil organic carbon dynamics and structural stability can aid to improve vegetable cropping systems sustainability in this region. In the present study, we evaluated the effect of seasonal tillage alterations (non-winter-tillage [NWT] and winter-tillage [WT]) on soil (0–10 cm) organic carbon (SOC) retention, soil aggregate stability, aggregate-associated C concentrations and CO₂ emission in a clay loam soil. Results indicated after 2 years that the plots under NWT had nearly 4% higher total SOC content and 9% higher proportion of large macro-aggregates (>2 mm) compared with WT plots in the 0–5 cm layer. Greater SOC and labile C within large macro-aggregates in the plots under NWT compared with WT were also observed in the surface layer only. Soil CO₂ emission rates were significantly greater in the WT plots than in the NWT plots during the dry season, but did not differ significantly between the WT and NWT plots during the rainy season. Our results demonstrated that the adoption of NWT should be a more sustainable management option than the traditional winter tillage for the maintenance of soil C and reduction of carbon dioxide emission in the rainfed vegetable cropping system of the mid-Yunnan plateau.

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1. Introduction

Soil organic carbon (SOC) is a major soil component affecting soil quality and agronomic sustainability, and agronomic practices significantly influence carbon sequestration in soils. Maintaining and improving SOC is crucial to alleviate deterioration of soil structure and emission of CO₂ in intensive cropping systems, because SOC is considered an important aggregate binding agent and a sink for carbon (Smith et al., 2012).

Tillage practices play an important role in the storage and release of SOC within the agricultural ecosystems' carbon cycle. Generally, continuous cropping results in a decline in SOC because of intensive tillage (Reeves, 1997), but this decrease is generally restricted to the surface soil. Research has shown that labile organic carbon is the major organic carbon pool depleted by increasing biological oxidation as a result of tillage (Elliott, 1986), and SOC loss within the macro-aggregate fraction is increased by

tillage practices (Andruschkewitsch et al., 2013). Razafimbelo et al. (2008) reported that macro-aggregates stored more organic carbon than micro-aggregates. The differences in C concentration within the aggregate classes can be linked to differences in the protective environment of aggregates and the stability of the SOC. Six and Paustian (2014) reported that the retention or loss of C within a given agricultural system is largely influenced by aggregate-associated soil organic matter.

The magnitude of CO₂ loss from soil due to tillage practices is highly related to the intensity of soil disturbance caused by tillage. Many authors have confirmed lower soil CO₂ emission under decreased tillage intensity which reduces soil disturbance and microbial activity (Jackson et al., 2003; Ussiri and Lal, 2009; Chaplot et al., 2015). However, Smith et al. (2012) reported greater soil CO₂ emissions from no-till soils than from conventionally tilled soils. Other authors reported no significant differences in emissions of CO₂ between no-till and conventionally tilled soils (Elder and Lal, 2008). There is little information on the timing of tillage and its effect on CO₂ loss. More information of tillage practice effects on soil CO₂ release is needed for designing agricultural practices aiming at sequestering C into soils.

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The mid-Yunnan plateau, southwestern China, is characterized by undulating topography, a monsoon season and naturally highly erodible soils. Vegetable–cereal crop rotations, which have been prevalent in this region for two decades, consist of vegetable cropping under plastic–mulched ridge–and–furrow systems in the rainy season and winter wheat or barley cropping in the dry season. In recent years, because of the high variability of rainfall in the mid-Yunnan plateau, bare fallow after winter tillage has been practiced by local farmers to sustain soil moisture in the dry season for the next vegetable crop. The objectives of this study were to determine the effects of winter-tillage vs. non-winter-tillage on SOC storage, soil aggregate stability and CO₂ emission rate over six field seasons.

2. Materials and methods

2.1. Site description and experimental design

A plastic mulching/rotation experiment was established in early summer 2010 at the Shuangshuan Research Station of Yunnan University, located in the mid-Yunnan plateau of southwestern China, at an elevation of 1950 m (Latitude: 24°36' N; Longitude: 102°41' E). This semi-humid region within the subtropical climatic zone is characterized by dry winters and moist summers. Mean annual air temperature in the area is 14.8 °C and mean annual rainfall is 891 mm (1981–2010), of which 80% falls between June and October (summer months). The soil type at the site is a red earth (Soil Taxonomy: Ferric Acrisol, according to FAO, 1998). Soil in the 0–10 cm layer consists of 10% sand, 50% silt, and 40% clay.

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. The previous crop prior to the experiment was sweet corn. There were 36 plots in total. The plot size was 10 m × 4 m with mean slope angles of 3–5°. In each plot, 120 broccoli seedlings were transplanted in the ridges of the narrow-plastic-mulch treatment or the wide-plastic-mulch treatment in early June. Zucchini seeds were planted in the same hole of plastic mulched bed after broccoli had been harvested at the end of August. Nitrogen and phosphorus fertilizers were applied for the two vegetables at the following rates: 420 kg N ha⁻¹ and 80 kg P ha⁻¹ (broccoli); 180 kg N ha⁻¹ and 80 kg P ha⁻¹ (zucchini). Fertilizer was not applied during the winter wheat growth period. Fertilizer inputs were not reduced in the winter wheat residue retention treatments because the nutrient inputs from stubble were very low (Zhang et al., 2013).

After the zucchini had been harvested at the end of October, soils of the broccoli-zucchini-winter wheat (B/Z/W) treatment were rotary cultivated to 0.15 m depth for winter wheat sowing. All of the wheat straw of those plots was incorporated into the soil by subsequent ridge-and-furrow system rebuilding operations in late May before the broccoli transplant. For the broccoli-zucchini-fallow (B/Z/F) treatment, after zucchini harvest, the plots were left fallow with the plastic mulch remaining intact until the next late May when the ridge and furrow systems were rebuilt after rotary cultivation to 0.15 m depth for broccoli transplant. In 2012 and 2013, in order to better understand the effects of winter tillage on soil CO₂ emission, 8 plots of B/Z/F treatment were cultivated at the same time as the B/Z/W treatment.

2.2. Soil sampling and analysis

Soil samples for soil organic carbon and soil structural stability measurements were taken in May before the broccoli

transplanting and in November after the zucchini harvest in 2012, 2013 and 2014. Six soil samples (10 cm × 10 cm × 5 cm) were randomly taken using a narrow spade from the ridges within each plot at 0–5 cm and 5–10 cm depths and then bulked to form one composite sample for each soil depth. Soil samples were air dried at 25 °C. Roots and large pieces of litter were removed from the soil samples before air drying. Sub-samples were taken from each plot soil sample and ground to pass through a 0.5 mm sieve for soil carbon analysis. Total organic carbon content was determined using the oil-bath potassium dichromate (K₂Cr₂O₇) titration method (Shi, 1998). Soil labile carbon was determined by the potassium permanganate method (Blair et al., 1995). Soil stable carbon was calculated as the difference between total organic carbon and labile carbon. All of the measurements were done in triplicate for each sample. The soil bulk density at the 0–5 cm and 5–10 cm depth was determined using the core method (Cresswell and Hamilton, 2002). The bulk of stainless ring was 200 cm³. Three core samples at each layer were collected randomly from the ridges in each plot in November, after the zucchini harvest, and in May, before transplanting the broccoli, in 2012, 2013 and 2014.

Sub-samples of soils from all plots were crushed to pass a through a 10 mm sieve after air-drying. Wet aggregate stability was determined on a 30 g dried soil sub-sample (10 mm). The sample was slaked in water for 5 min, and then wet-sieved through a column of sieves with a mesh opening of 2.00, 0.25 and 0.05 mm. The column of sieves was submerged in a cylinder of distilled water and driven up and down at a rate of 30 cycles per minute over a period of 2 min. The <0.05 mm fraction was determined by the pipette method (Chan et al., 2002) using the solution remaining in the container following sieving and after being shaken end-over-end 10 times prior to the analysis. The soil material remaining on each sieve was transferred to an aluminum container and dried at 105 °C. The proportion of aggregates in each particle size fraction was determined. The aggregate-associated carbon and labile carbon were determined for the soil material in each particle size fraction using the oil-bath potassium dichromate titration method and the potassium permanganate oxidation method, respectively. The C contribution of each fraction to the total C of the sample was calculated by grouping the fractions by size as follows, (a) <0.05 mm, (b) 0.05–0.25 mm (micro-aggregates), (c) 0.25–2 mm (small macro-aggregates), and (d) >2 mm (large macro-aggregates). All the measurements for each sample were done in triplicate.

2.3. In situ CO₂ flux, soil moisture, soil temperature

The CO₂ flux, soil moisture and soil temperature were determined in duplicate monthly from November, 2012 to December, 2014 along the ridges in the central part of each plot at intervals of 4 m. A flag was placed as a marker in the plot where CO₂ flux was measured throughout the study period. The CO₂ flux was measured with an environmental gas monitor chamber attached to a data logger (Qubit Systems' S151 CO₂, CB). The chamber was 15 cm tall, 10 cm in diameter, and had a maximum gas flow rate of 650 ml min⁻¹ and a measurement range of 0 to 2000 ppm CO₂. The chamber was placed at the soil surface for 2 min in each plot until CO₂ flux measurement was recorded in the data logger. Measurements were made between 8:30 and 11:30 A.M. local time on each sampling day. At the time of CO₂ measurement, soil temperature (0–10 cm) near the chamber was measured using a temperature probe attached to the data logger. Soil moisture (0–20 cm) in the vegetable beds (ridges) in each plot was measured by a time-domain reflectometer (Trime-Pico-lph TDR) at the same time as the CO₂ flux measurements.

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