Soil & Tillage Research 175 (2018) 178–186

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Research paper

Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system

Huili Zhao[a,b], Abdul Ghaffar Shar[a,b], Shuo Li[a,b], Yanlong Chen[a,b], Jianglan Shi[a,b], Xiaoyuan Zhang[a,b], Xiaohong Tian[a,b,*]

[a] College of Natural Resources and Environment, Northwest A & F University, Yangling 712100, Shaanxi, China
[b] Key Lab. of Plant Nutrition and the Agri-Environment in Northwest China, Ministry of Agriculture, Northwest A & F University, Yangling 712100, Shaanxi, China

ARTICLE INFO

Keywords:
Soil aggregation
Carbon content
Straw return mode
Maize–wheat double cropping system

ABSTRACT

Crop residue is a commonly used organic soil amendment in summer maize (June–October)–winter wheat (October–June of next year) rotation systems. However, the effects of different straw return modes on soil aggregation and soil organic carbon (SOC) stocks in different water-stable aggregates have not been extensively investigated in these cropping systems. The objective of this study was to quantify the long-term (7 yr) impact of C input on the SOC content of four soil aggregate size classes (large macroaggregates; small macroaggregates; microaggregates, silt plus clay fraction) and in explicit SOC fractions (free light fraction, free LF; intra-aggregate particulate organic matter, iPOM; mineral-associated matter, mSOM) within the top 40 cm of soil in a wheat–maize double cropping system in Northwest China. Four treatments were examined: (i) no return (control); (ii) return of wheat straw only (WR); (iii) return of maize straw only (MR); and (iV) return of both maize and wheat straw (MR-WR). Over the experimental period, the change in SOC under the four treatments ranged from −0.96 to 5.83 Mg ha^{-1} and a significant linear relationship between SOC change and cumulative C input (R^2 = 0.9882, $P < 0.05$) was observed. Relative to the control, the proportion of large and small macroaggregates in the 0–20 cm soil layer increased the most in MR-WR (32% and 24%), followed by MR (22% and 13%), and WR (11% and 10%). Straw return significantly increased the SOC content in each soil aggregate size class relative to no straw return. The order of SOC fractions with respect to SOC content was mSOM > fine iPOM > coarse iPOM > free LF. Straw return significantly increased the C stock in iPOM and mSOM relative to the control. Coarse iPOM was the most sensitive indicator of C change and mSOM was the main form of SOC under long-term straw return. A significant linear relationship existed between cumulative C input and the mass proportion of macroaggregates as well as the C content of SOC fractions (or aggregate fractions). Soil depth had a significant influence on almost all measurements, with greater values observed in the 0–20 cm layer than in the 20–40 cm layer. Overall, return of both maize and wheat straw was the best strategy for improving soil structure, soil organic carbon, and crop yield. However, straw return from one crop was sufficient to maintain initial SOC levels, and conserved straw could be used for cellulosic feedstocks.

1. Introduction

Soil is the largest pool of terrestrial organic carbon (OC), storing approximately 1580 Gt C (three times as much as the atmosphere), and thus plays an important role in the global C cycle (Jobbágy and Jackson, 2000). Carbon sequestration by soils helps stabilize the atmospheric CO_2 content, enhance soil fertility, and improve soil quality and structure (Wiesmeier et al., 2014).

Various factors influence soil organic carbon (SOC) content. For example regional climate, soil conditions, aggregate ability, and agricultural management practices (e.g., organic fertilizer application and straw return) can elevate SOC content by increasing C input and decreasing C output (Brar et al., 2013; Franzluebbers, 2005; Lal, 2004; Miller et al., 2004). Decreasing C output, promoting macroaggregate formation (Lugato et al., 2010) and SOC stabilization mechanisms are also vital for effectively maintaining SOC content. Identifying the size fractions of SOC that are involved in stabilization mechanisms is necessary to reliably assess soil C dynamics (Christensen, 2001; Von Lützow et al., 2007). Crop residue return is vital for increasing C input, maintaining soil C stocks, and mitigating climate change (Chatterjee, 2013; Dikgwatlhe et al., 2014) through the formation of humus and soil macroaggregates (Alidad et al., 2012; Liu et al., 2014). However, some

* Corresponding author at: College of Natural Resources and Environment, Northwest A & F University, Yangling 712100, Shaanxi, China.
E-mail addresses: txhong@hotmail.com, txhong@nwsuaf.edu.cn (X. Tian).

http://dx.doi.org/10.1016/j.still.2017.09.012
Received 29 October 2016; Received in revised form 21 August 2017; Accepted 17 September 2017
Available online 22 September 2017
0167-1987/

studies have identified negative effects of straw return on soil aggregates (Bossuyt et al., 2001; Soon and Lupwayi, 2012). This inconsistent research suggests that the effect of straw return on soil aggregation in agricultural soils is related to appropriate management practices and climate conditions.

Many studies have focused on the impacts of land use, tillage systems, manure application, and fertilization on soil aggregation in cereal and grassland ecosystems (Álvaro-Fuentes et al., 2009; Dou et al., 2016; Maillard et al., 2015; Tong et al., 2014). However, the impacts of straw return modes (e.g., double-crop straw return, single-crop straw return) on soil aggregation and the soil size fractions in double-cropping systems are unclear (Whitmore et al., 2014).

The Guanzhong Plain in Shaanxi Province of Northwest China is an important food-production area in the North Central Plain (Zhang et al., 2016) that accounts for approximately two-thirds of the entire province's total crop yield (Shaanxi Statistical Yearbook, 2012). The major agricultural planting system in this region, summer maize (*Zea mays* L.)–winter wheat (*Triticum aestivum* L.) double cropping, is characterized by intensive farming with high applications of mineral fertilizers (nitrogen and phosphorous) and no manure application; this results in high mineralization of native SOC due to increased microbial biomass, cellulose-decomposing enzymes, DOC, and N availability (Lu et al., 2014; Qiu et al., 2016). Additionally, in this planting system, high use of irrigation water and agricultural machinery (e.g., rotary cultivators) stimulates the degradation of existing soil organic matter. Over the past two decades, local farmers have adopted straw return to improve soil fertility. Return of all crop straw is infeasible due to the use of straw for cellulosic feedstock renewable energy, paper-making, and animal feed (Villamil et al., 2015). Therefore, to achieve a balance between soil conservation and cellulosic feedstock, it is necessary to adopt appropriate straw return management measures for improving soil structure and promoting sustainable grain production.

To fill this knowledge gap, the objectives of this study were to (i) assess the influence of straw return on soil aggregation and SOC aggregate size, (ii) determine the relative contributions of SOC fractions to SOC stabilization under straw return, and (iii) assess the relationships between residue C input and C stocks of SOC aggregates and fractions in the top 40 cm of soil under a wheat–maize double cropping system in the Guanzhong Plain. We hypothesized that straw return will increase the percentage of macroaggregates as well as the C content in soil aggregates of all SOC fractions.

2. Materials and methods

2.1. Site description

A field experiment was conducted from 2008 to 2015 at the Doukou Experimental Station (DKES) of Northwest A & F University (34°36′N and 108°52′E, 427.4 m above sea level), which is located in the Guanzhong Plain, Shaanxi Province, China. The experimental area is characterized by a semi-humid, temperate continental monsoon climate. The average annual rainfall is 527 mm, mainly occurring from June to September. The average annual sunshine duration is 2096 h, and the annual temperature average is 12.9 °C. The soil was classified as Eum-orthic Anthrosol (Udic Haplustalf in the USDA system) and had the following properties (0–20 cm) at the start of the experiment in 2008: pH 8.2 (1:1 soil: water), SOC 11.32 g kg^{-1}, total nitrogen (N) 0.68 g kg^{-1}, total phosphorus (P) 0.61 g kg^{-1}, total potassium (K) 21.53 g kg^{-1}, available phosphorus 52.6 mg kg^{-1}, available potassium 122.8 mg kg^{-1}, and mineral nitrogen 26.79 mg kg^{-1}.

2.2. Experimental design and management

Summer maize (June–October, cv. Nonghua 50) and winter wheat (October–next June, cv. Mianyang 26) were rotated each year for seven years. The experiment began with the maize season in June 2008 and ended after maize harvest in October 2015; thus, fifteen seasonal crops successively grew in the same experimental plots. Maize was planted at a rate of 63,000 seeds ha^{-1} in mid-June after wheat harvest and harvested in late September or early October. Wheat was planted after maize harvest at a rate of 220 kg ha^{-1} and harvested in early June of the following year.

Four treatments were implemented in the experimental plots as follows: (1) no straw return (control); (2) return of wheat straw only (WR); (3) return of maize straw only (MR); and (4) return of both maize and wheat straw (MR-WR). The plots were arranged in a randomized complete block design with four replications, and each plot was 12.5 × 56 m. In the control plots, the aboveground portion of straw was removed from each plot after harvest (very little stubble was returned to the field); in the straw return plots, crop straw was cut into 10-cm long segments and uniformly distributed over each plot after harvest.

Maize was planted in mid-June after wheat harvest and harvested in early October. The growing time of this maize variety is 105 days (Gu et al., 2017). After maize harvest, the entire soil surface of all plots was tilled three times with a rotavator to ∼15 cm depth, after which the maize straw was crushed and incorporated into the surface soil of straw return treatments by rotary tillage. In all plots, 120 kg ha^{-1} N and 102 kg ha^{-1} P_2O_5 were incorporated into the 0–15 cm soil layer with rotary tillage. Nitrogen and phosphorus were applied as urea and diammonium phosphate, respectively. All plots were watered by strip irrigation (2.5 × 56 m) using underground or reservoir water (∼60 mm) during the seedling and tillering stages of wheat. After wheat harvest, wheat straw was incorporated into the 0–5 cm soil layer of straw return treatments by rotary tillage; all plots were fertilized with mixed granules of 67.5 kg ha^{-1} N and 22.5 kg ha^{-1} P_2O_5 to promote wheat straw decomposition and maize seed germination, emergence, and early growth. During the tasseling stage of maize, plots were fertilized with 120 kg ha^{-1} N, followed by irrigation with 60 mm of water to promote the growth and maturity of maize. To control pests and weeds, herbicides (Tribenuron-methyl and 2.4-D for wheat; Atrazine and Propisochlor for maize) and pesticides (Methamidophos, Omethoate, and Triadimefon) were managed during both maize and wheat seasons in accordance with conventional weed and pest management practices.

2.3. Crop biomass, yield measurements, and carbon input estimates

Samples were collected at crop maturity; maize grain and aboveground straw were manually harvested in triplicate from the center (10 m^2) of each plot. After air-drying, portions of grain and straw were oven-dried at 60 °C for biomass determination. Similarly, wheat samples were collected from two separate areas (2 m^2) in the center of each plot, and the dry weights of grain and straw were determined after separation and oven-drying at 60 °C.

The amount of belowground residue, including roots and rhizodeposition, was estimated from the ratio of roots to straw (Kong et al., 2005). The amount of residue and C derived from rhizodeposition was assumed to be equal to that originating from roots (Bolinder et al., 1999). For both crops, the C content was assumed to be 40% of the biomass (Johnson et al., 2006). The ratio of stubble to straw biomass was approximately 10% and 20% for maize and wheat, respectively. The total plant-derived biomass and C content, including crop residues (straw, stubble, roots, and rhizodeposition), were estimated based on the above information.

2.4. Soil sampling

Soil samples were collected from two soil layers (0–20 cm and 20–40 cm) in mid-October 2015 after maize harvest with a distance of 3.0 m between each sampling point. Two composite soil samples (each from 5 sub-samples) were collected from the two soil layers in each plot (2 composites × 16 plots × 2 depths). A total of 64 soil samples were