Decomposition characteristics of organic materials and their effects on labile and recalcitrant organic carbon fractions in a semi-arid soil under plastic mulch and drip irrigation postprint

Authors: Wu, Jinggui

Date: 2017-12-18T00:00:00+00:00

Abstract

Labile organic carbon (LC) and recalcitrant organic carbon (RC) are two major fractions of soil organic carbon (SOC) and play a critical role in organic carbon turnover and sequestration. The aims of this study were to evaluate the variations of LC and RC in a semi-arid soil (Inner Mongolia, China) under plastic mulch and drip irrigation after the application of organic materials (OMs), and to explore the effects of OMs from various sources on LC and RC by probing the decomposition characteristics of OMs using in-situ nylon mesh bags burying method. The field experiment included seven treatments, i.e., chicken manure (CM), sheep manure (SM), mushroom residue (MR), maize straw (MS), fodder grass (FG), tree leaves (TL) and no OMs as a control (CK). Soil LC and RC were separated by Huygens D' s method (particle size-density), and the average soil mass recovery rate and carbon recovery rate were above 95%, which indicated this method was suitable for carbon pools size analysis. The LC and RC contents significantly ($P<0.01$) increased after the application of OMs. Moreover, LC and RC contents were 3.2%-8.6% and 5.0%-9.4% higher in 2016 than in 2015. The applications of CM and SM significantly increased ($P<0.01$) LC content and LC/SOC ratio, whereas they were the lowest after the application of TL. However, SOC and RC contents were significantly higher ($P<0.01$) after the applications of TL and MS. The correlation analysis indicated the decomposition rate of OMs was positively related with LC content and LC/SOC ratio. In addition, lignin, polyphenol, WOM (total water-soluble organic matter), WHA (water-soluble humic acid), HSL (humic-like substance) and HAL (humic acid-like) contents in initial OMs played important roles in SOC and RC. In-situ nylon mesh bags burying experiment indicated the decomposition rates of CM, SM and MS were significantly higher than those of MR, FG, and TL. Furthermore, MS could result in more lignin derivatives, WHA, and HAL polymers in shorter time during the decomposition process. In conclusion, the application of MS in the semi-arid soil under a long-term plastic mulch and drip irrigation condition could not only improve soil fertility, but also enhance soil carbon sequestration.

Full Text

Decomposition Characteristics of Organic Materials and Their Effects on Labile and Recalcitrant Organic Carbon Fractions in a Semi-Arid Soil Under Plastic Mulch and Drip Irrigation

HU Juan, WU Jinggui*, QU Xiaojing
College of Resource and Environmental Science, Jilin Agricultural University, Changchun 130118, China

Abstract: Labile organic carbon (LC) and recalcitrant organic carbon (RC) represent two major fractions of soil organic carbon (SOC) that play critical roles in organic carbon turnover and sequestration. This study evaluated variations in LC and RC in a semi-arid soil (Inner Mongolia, China) under plastic mulch and drip irrigation following the application of organic materials (OMs), and explored how OMs from various sources affect LC and RC by examining decomposition characteristics using an in-situ nylon mesh bag burial method. The field experiment included seven treatments: chicken manure (CM), sheep manure (SM), mushroom residue (MR), maize straw (MS), fodder grass (FG), tree leaves (TL), and a control without OMs (CK). Soil LC and RC were separated using Huygens D' s method (particle size-density), with average soil mass recovery and carbon recovery rates exceeding 95%, confirming the method' s suitability for carbon pool size analysis. LC and RC contents increased significantly ($P<0.01$) after OM application and were 3.2%-8.6% and 5.0%-9.4% higher in 2016 than in 2015, respectively. CM and SM applications significantly increased ($P<0.01$) LC content and the LC/SOC ratio, while TL application produced the lowest values. Conversely, SOC and RC contents were significantly higher ($P<0.01$) following TL and MS applications. Correlation analysis revealed that OM decomposition rate was positively related to LC content and the LC/SOC ratio. Additionally, lignin, polyphenol, WOM (total water-soluble organic matter), WHA (water-soluble humic acid), HSL (humic-like substance), and HAL (humic acid-like) contents in initial OMs played important roles in SOC and RC. The in-situ nylon mesh bag experiment showed that decomposition rates of CM, SM, and MS were significantly higher than those of MR, FG, and TL. Furthermore, MS produced more lignin derivatives, WHA, and HAL polymers in a shorter time during decomposition. In conclusion, applying MS to semi-arid soils under long-term plastic mulch and drip irrigation can improve both soil fertility and carbon sequestration.

Keywords: organic materials; labile organic carbon; recalcitrant organic carbon; decomposition characteristics; plastic mulch; drip irrigation; Inner Mongolia

*Corresponding author: WU Jinggui (E-mail: wujingguiok@163.com)

Received 2017-04-06; revised 2017-10-31; accepted 2017-11-13

1 Introduction

Soil organic carbon (SOC) plays a vital role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention, and supporting soil biological activity (Loveland and Webb, 2003; Lal, 2004; Sparling and Schipper, 2004; Haynes, 2005). Simultaneously, SOC serves as an indicator of sustainable land management (Nandwa, 2001) and critically determines responses to nitrogen and phosphorus fertilization. Although the labile organic carbon (LC) fraction accounts for only a small portion of total SOC, it directly participates in soil biochemical processes and plays an essential role in soil health (Haubensak et al., 2002; McLauchlan and Hobbie, 2004; Cookson et al., 2005). Separation techniques for LC can be classified as physical, chemical, or biological methods, with chemical methods being most commonly used in previous studies. LC fractions identified through chemical methods include water-soluble organic carbon (WOC), dissolved organic carbon (DOC), microbial biomass carbon (MBC), particulate organic carbon (POC), and permanganate-oxidized carbon (POXC) (Meng et al., 2013; Plaza-Bonilla et al., 2014). However, physical methods cause less damage to organic carbon structure than chemical methods, and the separated components can better reflect the structure and function of undisturbed SOC (Zhang et al., 2011).

Based on carbon cycle characteristics in the Markov Chain Monte Carlo (MCMC) model (Müller et al., 2004), Huygens et al. (2007) recently improved the soil separation method of Meijboom et al. (1995), asserting that SOC could be divided into LC and recalcitrant organic carbon (RC) through this physical method. LC and RC represent two important components of SOC, and their ratios to SOC (i.e., LC/SOC and RC/SOC) can serve as indicators to describe SOC turnover and sequestration (Yu et al., 2015).

Management strategies affecting SOC components have recently received considerable attention (Knoblauch et al., 2011; Du et al., 2013; Troy et al., 2013). One important strategy for sustainable agricultural production systems involves applying organic materials (OMs) to soils (Schmidt et al., 2011). Gougoulias et al. (2014) and Liu et al. (2016) demonstrated that OM application significantly contributed to LC content, primarily because OMs input into soil provide a carbon source for soil microorganisms. Liang (2012) and Chen et al. (2015) also found that OM application could significantly affect MBC, POC, and DOC contents. Moreover, Li et al. (2016) indicated that soil DOC and MBC contents increased significantly after applying straw, mushroom residue, and manure.

Numerous studies have examined the effects of OM application on LC fractions using chemical methods. For example, Singh et al. (2009) found that OM quality importantly influenced short-term soil carbon dynamics, and SOC and LC amounts were closely related to the types and properties of exogenous OMs (Manna et al., 2005). However, relatively few studies have examined LC and RC fractions separated by Huygens D' s method (2007) or investigated relationships between OM chemical compositions and SOC fractions.

Integrating water-saving drip irrigation with evaporation-reducing plastic film mulch is particularly suitable for improving water use efficiency, especially in semi-arid areas of western China. In recent years, plastic mulch and drip irrigation have been applied across approximately 4.686×10 hm^2 in Inner Mongolia. Jiang et al. (2014) and Yin et al. (2014) found that plastic film mulch could alter soil physical, chemical, and biological properties, promote decomposition of soil organic matter, and enhance transformation and release of soil nutrients, thereby increasing soil nutrient availability and fertility. Li et al. (2007) found that corn biomass and yield increased under plastic film mulch, resulting in more corn residue returned to soil. Li et al. (2009) also found that plastic film mulch promoted organic carbon decomposition and decreased light fraction organic carbon content in topsoil. Numerous studies have investigated the effects of plastic mulch and drip irrigation on LC in different soils; however, little information is available regarding their effects on both LC and RC.

This study aimed to evaluate variations in LC and RC separated by Huygens D' s method in a semi-arid soil under plastic mulch and drip irrigation after applying six different OMs, including natural organic materials (maize straw, fodder grass, and tree leaves), livestock manures (chicken manure and sheep manure), and half-decomposed organic materials (mushroom residue). Additionally, an in-situ nylon mesh bag burial experiment was conducted to explore decomposition characteristics and chemical composition variations of different OMs. We hypothesized that OM application would increase SOC, LC, and RC contents and affect SOC turnover and sequestration in semi-arid soils under plastic mulch and drip irrigation. Moreover, OM decomposition rates and chemical compositions would play important roles in SOC fractions.

2.1 Experimental Site

The experiment was conducted in Tumuji Town (46°17 N, 123°00 E), located in Jalaid Banner, Hinggan League, Inner Mongolia, China, which belongs to semi-arid regions. The annual average temperature is 4.0°C, mean annual precipitation is 300–450 mm, and the frost-free period is approximately 150 days. Average annual sunshine hours total 2592 h, and total solar radiation is 5362.46 MJ/(m^2 · a). The effective accumulated temperature 10°C is about 2700°C–3300°C. The soil is classified as Chernozem, with a pH of 8.2 and containing 19.8 g/kg organic matter, 6.55 mg/kg available phosphate, 51.36 mg/kg available potassium, and 84.82 mg/kg available nitrogen.

2.2.1 Field Experiment with OM Application

The field experiment was conducted in May 2015 and 2016. The OMs used included chicken manure (CM), sheep manure (SM), mushroom residue (MR), maize straw (MS), fodder grass (FG), tree leaves (TL), and a control without OMs (CK). CM and SM were collected from chicken and sheep breeding farms, respectively. MR was the residue from edible fungus culture medium produced with corn as raw material. MS was maize straw, and TL was poplar leaves. FG was collected from Jalaid Banner pasture. The basic properties of initial OMs are shown in Table 1 . The maize variety used was XianYu 335. Each plot measured 5 m × 10 m. The field was arranged in a randomized design with three replicates per treatment. The mechanized coated drip irrigation cultivation technique was used during planting. OMs were manually applied to ridges after ridging in both 2015 and 2016. Ridge height was 10 cm. Carbon input was 7719 kg C/hm², with each organic material treatment receiving equivalent amounts in 2015 and 2016. Application rates were 33,151 kg/hm² for CM, 27,708 kg/hm² for SM, 22,953 kg/hm² for MR, 18,000 kg/hm² for MS, 22,265 kg/hm² for FG, and 19,415 kg/hm² for TL. Each plot received urea (210 kg N/hm²), superphosphate (67 kg P/hm²), and potassium chloride (87 kg K/hm²). Soil samples were collected from the junction of ridge and furrow at 0–20 cm depth in October 2015 and 2016. Five samples per plot were collected following an "S" pattern. Samples were then air-dried, passed through a 2-mm sieve after removing crop residues and stones.

2.2.2 Field Experiment with In-Situ Nylon Mesh Bag Burial

The in-situ nylon mesh bag burial experiment was conducted simultaneously with similar field management to the OM application experiment. Six treatments were included: CM, SM, MR, MS, FG, and TL. Each treatment had three replicates, with each plot covering 1.7 m × 3.6 m. Raw materials of MR, TL, CM, and SM were crushed into crumbs, while MS and FG were cut into 2-3 cm segments. Each OM type (20 g) was placed into 300-mesh nylon bags (20 cm × 15 cm) and sealed. A total of 24 nylon mesh bags were buried per plot. Bags were placed flat without overlap directly below the drip irrigation belt at 20-cm intervals in 10-cm deep soil. Three nylon mesh bags from each plot were randomly collected at 30, 60, 90, 120, 150, 180, 360, and 540 days after burial, then returned to the laboratory and stored after cleaning.

Lignin and cellulose were measured using Van Soest acid detergent fiber method (Van Soest, 1963). Organic C was measured by exogenous thermal process with potassium dichromate (Walkley and Black, 1934). Polyphenol was measured by ferrous tartrate method (Turkmen et al., 2006). Total N was determined by Kjeldahl method. Water-soluble organic matter and humic-like substance fractions were extracted according to Wu et al. (2004).

Table 1 Basic properties of the initial organic materials

Material	Organic C (g/kg)	Total N (g/kg)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Polyphenol (%)	Lignin/N	Quality class
Chicken manure	232.84±2.31e	15.19±0.67a	7.02±0.93	4.16±0.22d	2.29±0.33	0.69±0.05b	1.51±0.32d	-
Sheep manure	278.58±2.01d	9.82±0.38bc	20.53±1.24c	14.13±0.72b	2.60±0.75	0.75±0.08b	2.65±0.19d	-
Mushroom residue	336.29±3.34c	11.06±0.53b	12.76±1.54d	5.15±0.21d	6.90±0.40	0.72±0.09b	6.24±0.12cd	IM
Maize straw	428.85±2.56a	6.13±0.72	37.81±2.12a	23.68±1.15a	5.30±0.10	0.88±0.07b	8.65±0.43b	-
Fodder grass	346.68±4.18c	16.75±1.02a	25.64±2.00	16.25±1.07b	8.49±0.83	0.81±0.04b	5.07±0.41cd	-
Tree leaves	397.57±1.28b	8.72±0.68b	13.47±0.68	8.89±0.58c	11.50±0.16	1.75±0.03a	13.19±0.92a	-

Note: IM, intermediate quality. Data with the same lowercase letter within the same row do not differ significantly at the 5% level according to the least significant difference test. Values are mean ± standard error.

2.3 Separation Method for Labile Organic Carbon (LC) and Recalcitrant Organic Carbon (RC)

Soil LC and RC fractions were separated using Huygens D' s method. Each sample was processed three times with the following steps: 50 g of air-dried soil passing through a 2-mm sieve was placed on a 0.25-mm sieve and wetted with deionized water. The sieve set (0.25-, 0.15-, and 0.05-mm sieves) was placed in a wet sieve barrel, water was added to immerse the soil on top of the 0.25-mm sieve, and wet-sieving was performed with a sieving machine for 30 minutes. Size fractions retained on the 0.25-mm and 0.15-mm sieves were washed into a bucket and swirled with injected deionized water. The upper turbid liquid was poured out and collected until the washing solution became clear to separate macro organic matter (>0.15 mm MOM) and mineral fraction (>0.15 mm MF) by decantation. The MOM, MF, 0.05–0.15 mm fraction, and <0.05 mm fraction (centrifuged at 3000 r/min for 5 min) were then collected. Each fraction was oven-dried at 55°C and weighed. Dried soils were ground with a planetary ball mill and stored for subsequent carbon analysis.

LC was defined as carbon content in MOM per 1 kg of original soil. RC was defined as the sum of carbon content in MF, 0.05–0.15 mm fraction, and <0.05 mm fraction per 1 kg of original soil. Mass recovery referred to the percentage of the sum of different soil grade weights relative to total soil weight (50 g).

Carbon recovery represented the sum of carbon content in different soil grades relative to carbon content in the total soil amount.

2.4 Data and Statistical Analyses

Decomposition percentage (%) = (mass of initial OMs -mass of residue OMs) / mass of initial OMs × 100

Cellulose decomposition percentage (%) = (content of initial OMs -content of residue OMs) / content of initial OMs × 100

Residual quantities of OMs during decomposition were fitted by exponential equation:

$$y = a + b \times e^{-k \times t}$$

where y (g) is residual quantity at time t; k is the decomposition rate constant calculated by least-squares method, indicating decomposition speed; b (g) is mass lost; and a (g) is the asymptote value of y when t approaches infinity.

Carbon released quantities from OMs during decomposition were calculated as:

$$C_t = \frac{C_0 \times M_0 - C_t \times M_t}{M_0} \times 1000$$

where C_0 is C content of initial OMs (g/kg); M_0 is mass of initial OMs (g); C_t is C content of OMs at time t (g/kg); and M_t is mass of OMs at time t (g).

Carbon released quantities from OMs during decomposition were fitted by first-order kinetic equation:

$$C_t = C_0 \times (1 - e^{-k_0 \times t})$$

where k_0 is the carbon decomposition rate constant calculated by least-squares method.

Results were initially compiled using Excel 2010 (Microsoft, Redmond, WA, USA). All analyses were performed with three replicates. Data were analyzed using analysis of variance (ANOVA). Multiple comparisons were conducted using Duncan’ s new multiple range test (DMRT). Significant differences between treatments were determined at 95% and 99% probability levels. Graphical material was prepared using Origin 2007 (Originlab, Northampton, USA).

3.1 Soil Organic Carbon (SOC)

Compared with CK, SOC contents increased significantly (P<0.01) after OM application (Fig. 1 [Figure 1: see original paper]). In both 2015 and 2016, SOC contents followed the descending order TL > MS > FG > MR > SM > CM, with SOC contents in 2016 being 6.7%-12.6% higher than in 2015. Compared with CK, SOC contents after TL and MS applications increased by 39.5% and 36.2%, respectively, in 2016. SOC contents after TL application were 9.5%, 15.0%, 19.2%, and 20.7% higher than those of FG, MR, SM, and CM, respectively, in 2016 (P<0.01). Meanwhile, SOC contents after MS application were 6.9%, 12.2%, 16.3%, and 17.8% higher than those of FG, MR, SM, and CM, respectively, in 2016 (P<0.01). However, SOC content after TL application was 2.5% higher than that after MS application (P<0.05) in 2016.

Fig. 1 Soil organic carbon (SOC) contents after OM application in 2015 and 2016. Error bars represent standard deviations. Different lowercase and capital letters above bars indicate significance at P<0.05 and P<0.01 levels, respectively, among treatments within the same year. CK, control; MR, mushroom residue; CM, chicken manure; SM, sheep manure; TL, tree leaves; MS, maize straw; FG, fodder grass. Abbreviations apply hereafter.

3.2 Labile Organic Carbon (LC) and Recalcitrant Organic Carbon (RC)

The average mass recovery rate and carbon recovery rate were 95.53% (94.51%-96.32%) and 95.87% (94.54%-96.25%), respectively, after separation. This simple separation method was suitable for carbon pool size analysis as errors were controlled within a reasonable range.

Compared with CK, LC and RC contents increased significantly (P<0.01) after OM application (Table 2). Moreover, LC and RC contents were 3.2%-8.6% and 5.0%-9.4% higher in 2016 than in 2015, respectively. LC contents increased most after CM and SM applications, rising by 28.9% and 30.7%, respectively, in 2016 compared with CK. Additionally, LC contents after MS, MR, and FG applications were 10.8%, 9.4%, and 8.5% higher than after TL application (P<0.01) in 2016, respectively. RC contents after TL and MS applications increased by 38.4% and 33.0%, respectively, in 2016 compared with CK. RC contents after TL application were 11.7%, 17.0%, 21.8%, and 27.5% higher than those of FG, MR, SM, and CM, respectively, in 2016 (P<0.01). RC contents after MS application were 7.3%, 12.3%, 17.0%, and 22.4% higher than those of FG, MR, SM, and CM, respectively, in 2016 (P<0.01). RC content after TL application was 4.2% higher than that after MS application (P<0.01) in 2016.

Table 2 LC and RC contents after OM application in 2015 and 2016

SOC component	Year	CK	CM	SM	MR	TL	MS	FG
LC (g/kg)	2015	1.10±0.01eE	1.40±0.02cC	1.49±0.01aA	1.43±0.01bB	1.31±0.01dD	1.40±0.02cC	1.34±0.01cC
	2016	1.19±0.03dC	1.46±0.06bB	1.54±0.02abA	1.56±0.03aA	1.34±0.02cB	1.48±0.05bB	1.45±0.04bB
RC (g/kg)	2015	11.32±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.08cC
	2016	11.60±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]0.269cC

Note: SOC, soil organic carbon; LC, labile organic carbon; RC, recalcitrant organic carbon; OMs, organic materials. Different lowercase and capital letters within the same row indicate significance at P<0.05 and P<0.01 levels, respectively, among treatments within the same year. Values are mean ± standard error.

Two-way ANOVA revealed that both OM treatments and years were main factors influencing SOC, LC, and RC contents (Table 3). Interactions between OM treatments and years were significant for SOC and RC contents but not significant for LC content.

Table 3 Significant effects of OM treatments, years, and their interactions on SOC, LC, and RC contents

Main effect	SOC		LC		RC	
	Mean square	F value	Mean square	F value	Mean square	F value
OM treatment (O)	15.63	312.67**	0.12	120.35**	13.21	264.18**
Year (Y)	12.45	249.12**	0.08	80.24**	10.89	217.82**
O × Y	1.23	24.65**	0.01	10.21NS	1.01	20.18**

Note: ** indicates significance at P<0.01 level; NS, not significant.

3.3 Ratios of Labile Organic Carbon and Recalcitrant Organic Carbon to Soil Organic Carbon (LC/SOC and RC/SOC)

Allocation proportions of LC fractions differed significantly after OM application (Fig. 2 [Figure 2: see original paper]). Compared with CK, the LC/SOC ratio after CM and SM applications increased significantly (P<0.01) by 31.7% and 21.7% in 2015, and by 11.5% and 11.6% in 2016, respectively. The LC/SOC ratio decreased significantly (P<0.01) after TL application in 2015, and after TL and MS applications in 2016. However, compared with CK, the RC/SOC ratio after CM and SM applications decreased with no significant differences in either year. Among the six OM types, RC/SOC ratio was highest after TL application, followed by MS.

Fig. 2 Proportion of soil organic carbon components after OM application in 2015 and 2016. CL, carbon loss quantities in separation; LC, labile organic carbon; RC, recalcitrant organic carbon. Different lowercase and capital letters indicate significance at $P<0.05$ and $P<0.01$ levels, respectively, among treatments.

3.4 Pearson's Correlation Coefficient (r) Between Chemical Compositions of OMs and SOC Fractions

Correlation analysis explored relationships between OM chemical compositions and SOC fractions (Table 4). The most important chemical compositions affecting SOC content were lignin ($r=0.709$, $P<0.01$), WOM ($r=0.754$, $P<0.01$), WHA ($r=0.652$, $P<0.05$), HSL ($r=0.685$, $P<0.05$), polyphenol ($r=0.655$, $P<0.05$), and HAL ($r=0.619$, $P<0.05$). LC content showed negative relationships with C/N ratio ($r=-0.817$, $P<0.01$) and WHA ($r=-0.640$, $P<0.01$). RC content showed positive relationships with lignin ($r=0.633$, $P<0.05$), polyphenol ($r=0.642$, $P<0.05$), lignin/N ratio ($r=0.627$, $P<0.05$), WOM ($r=0.733$, $P<0.01$), WHA ($r=0.750$, $P<0.01$), HSL ($r=0.747$, $P<0.01$), and HAL ($r=0.725$, $P<0.01$). The most important factor affecting LC/SOC ratio was C/N ratio ($r=-0.718$, $P<0.01$). Lignin ($r=0.647$, $P<0.05$) and lignin/N ratio ($r=0.738$, $P<0.01$) played important roles in RC/SOC ratio. Additionally, a positive relationship was found between OM decomposition rates and LC content ($r=0.507$, $P<0.05$) and LC/SOC ratio ($r=0.734$, $P<0.01$).

Table 4 Pearson' s correlation coefficient (r) between chemical compositions of OMs and SOC fractions in 2016

SOC fraction	Organic C	Total N	C/N	Cellulose	Hemicellulose	Lignin	Polyphenol	Lignin/N	Decomposition rate
SOC	0.709**	0.655*	0.754**	0.652*	0.685*	0.619*	-	-	-
LC	-	-	-0.817**	-	-	-0.640*	-	-	0.507*
RC	0.633*	0.642*	0.627*	0.773**	0.750**	0.747**	0.725**	-	-
LC/SOC	-	-	-0.718**	-	-	-	-	0.734**	-
RC/SOC	0.647*	-	-	-	-	0.738**	-	-	-

Note: LC/SOC, ratio of labile organic carbon to soil organic carbon; RC/SOC, ratio of recalcitrant organic carbon to soil organic carbon; WOM, total water-soluble organic matter; WLOM, water-soluble litter-molecular organic matter; WHA, water-soluble humic acid; HSL, humic-like substance; FAL, fulvic acid-like; HAL, humic acid-like. r values are coefficients based on Pearson' s correlation analysis (n=21). * and ** indicate significance at $P<0.05$ and $P<0.01$

levels, respectively. Decomposition rate of OMs was calculated from organic carbon content over 540 days.

3.5 Residual Quantities and Carbon Released Quantities of OMs During Decomposition

The OM decomposition process could be divided into three stages: 0–90 days as a "quick decomposition period," 90–180 days as a "slow decomposition period," and 180–540 days as a "stable decomposition period" (Fig. 3 [Figure 3: see original paper]). Within 90 days, OM decomposition rate exceeded 70%. After 540 days, residual quantities of CM, SM, and MS decreased to 5.69, 6.11, and 6.53 g from the initial 20 g, whereas those of MR, FG, and TL decreased to 8.05, 8.84, and 10.32 g, respectively. Moreover, decomposition rates of CM, SM, and MS (71.55%, 68.16%, and 68.21%) were higher than those of MR, FG, and TL (58.64%, 55.28%, and 47.95%), respectively.

Carbon release quantities from OMs initially increased rapidly then stabilized during decomposition (Fig. 4 [Figure 4: see original paper]). Carbon release quantity from MS was higher than other OMs at each period. Within 90 days, carbon release quantities from OMs exceeded 65%. After 540 days, carbon release quantities from MS, TL, MR, FG, SM, and CM were 6.38, 4.85, 4.71, 4.64, 4.37, and 3.80 g, respectively.

Fig. 3 Dynamic changes in residual quantities of OMs during decomposition under different treatments. Error bars represent standard deviations.

Fig. 4 Dynamic changes in carbon release quantities from OMs during decomposition under different treatments. Error bars represent standard deviations.

Changes in residual quantities of OMs during decomposition were well fitted by the first-order kinetic equation ($y = a + b \times e^{-k\times t}$) (Table 5), with high correlation (R^2>0.98). The k values for CM, SM, and MS were higher, requiring 61, 63, and 69 days, respectively, for half decomposition. In contrast, k values for MR, FG, and TL were lower, requiring 117, 161, and 590 days, respectively, for half decomposition. Changes in carbon release quantities from OMs during decomposition were fitted by the first-order kinetic equation with high correlation (R^2>0.98). The C_0 value for MS was highest (6.11), followed by TL (4.75), while those for CM and SM were lower (3.66 and 4.18, respectively). The k_0 value for SM was highest (0.0203), followed by MS (0.0194) and CM (0.0189), while TL had the lowest value (0.0117).

Table 5 Fitted equations for residual quantities and carbon release quantities of OMs over decomposition time

Treatment	$y = a + b \times e^{-k\times t}$	R^2	$C_t = C_0 \times (1 - e^{-k_0\times t})$	R^2
CM	$y = 5.69 + 14.31e^{-0.0114t}$	0.99	$C_t = 3.66(1 - e^{-0.0189t})$	0.99

Treatment	$y = a + b \times e^{-k \times t}$	R^2	$C_t = C_0 \times (1 - e^{-k_0 \times t})$	R^2
SM	$y = 6.11 + 13.89e^{-0.0110t}$	0.99	$C_t = 4.18(1 - e^{-0.0203t})$	0.99
MR	$y = 8.05 + 11.95e^{-0.0059t}$	0.99	$C_t = 4.71(1 - e^{-0.0132t})$	0.99
MS	$y = 6.53 + 13.47e^{-0.0100t}$	0.99	$C_t = 6.11(1 - e^{-0.0194t})$	0.99
FG	$y = 8.84 + 11.16e^{-0.0043t}$	0.98	$C_t = 4.64(1 - e^{-0.0125t})$	0.99
TL	$y = 10.32 + 9.68e^{-0.0012t}$	0.99	$C_t = 4.75(1 - e^{-0.0117t})$	0.99

Note: R^2 is determination coefficient; y is residual quantity at time t; k is decomposition rate constant; b is mass lost; a is asymptote value when t approaches infinity; C_t is carbon release quantity at time t; C_0 is carbon mineralization potential; k_0 is carbon decomposition rate constant.

3.6 Residual Quantities of Cellulose and Lignin in OMs During Decomposition

Residual cellulose content trends declined rapidly then stabilized during decomposition, similar to OM residual quantity trends (Fig. 5 [Figure 5: see original paper]). Cellulose contents in FG and TL decomposed quickly during 0–60 days, while those in MS, MR, CM, and SM decomposed rapidly during 0–90 days. After 540 days, cellulose decomposition percentages followed the descending order MS > CM > FG > MR > TL > SM, reaching 64.87%, 62.67%, 62.44%, 55.93%, 51.36%, and 50.14%, respectively.

Residual lignin contents in OMs increased during early decomposition. Lignin contents in MS, CM, and SM increased mainly during 0–60 days, while those in TL, FG, and MR increased primarily during 0–90 days. Compared with initial OM lignin contents, after 540 days lignin contents in TL, MS, MR, FG, SM, and CM increased by 26.77%, 21.36%, 19.14%, 16.09%, 11.84%, and 10.68%, respectively.

Fig. 5 Dynamic changes in residual quantities of cellulose (a) and lignin (b) contents in OMs during decomposition.

3.7 Water-Soluble Organic Matter in OMs During Decomposition

Dynamic changes in water-soluble organic matter (WLOM) of OMs during decomposition are presented in Table 6 . WLOM contents generally declined during decomposition, with only MS and TL showing increases at 90 days. WOM and WHA contents exhibited rising trends at 90 days. WOM contents in MS, FG, and MR increased significantly and were sustained longer, while those in CM, SM, and TL increased slightly and were sustained for shorter durations. WHA contents in MS increased more than other OMs.

Table 6 Dynamic changes in water-soluble organic matter of OMs during decomposition

OMs	Components	0	30	60	90	120	150	180	360	540
CM	WOM	12.82±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.05
	WLOM	7.33±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03
	WHA	5.49±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.08
SM	WOM	15.55±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.10
	WLOM	6.47±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.05
	WHA	9.07±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03
MR	WOM	13.71±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.14
	WLOM	5.20±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.17
	WHA	8.50±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.02
MS	WOM	11.04±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.13
	WLOM	4.91±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.06
	WHA	6.13±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.17
FG	WOM	17.01±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.05
	WLOM	6.57±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.09
	WHA	10.44±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.08
TL	WOM	15.86±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.17
	WLOM	7.68±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.11
	WHA	8.19±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03

Note: WOM, total water-soluble organic matter; WLOM, water-soluble littermolecular organic matter; WHA, water-soluble humic acid. Values are mean ± standard error.

3.8 Humic-Like Substance in OMs During Decomposition

Dynamic changes in humic-like substance of OMs during decomposition are shown in Table 7 . HSL and HAL contents exhibited rising trends during decomposition. HSL and HAL contents in MS increased at 60 days and reached maximum values at 90 days. Moreover, HSL and HAL contents in MS were significantly higher than other OMs at each period. HSL and HAL contents in CM, SM, MR, TL, and FG increased at 90 days, with TL, MR, and FG showing large increases.

Table 7 Dynamic changes in humic-like substance of OMs during decomposition

OMs	Components	0	30	60	90	120	150	180	360	540
CM	HSL	7.93±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.39
	FAL	4.47±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.16
	HAL	3.46±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.08
SM	HSL	6.16±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.05
	FAL	4.19±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.06
	HAL	1.97±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03
MR	HSL	8.19±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.61
	FAL	2.16±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.05
	HAL	6.03±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03
MS	HSL	10.28±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.16
	FAL	5.97±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.11
	HAL	4.32±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.08
FG	HSL	17.45±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.46
	FAL	9.90±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.07
	HAL	7.55±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.52
TL	HSL	14.91±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.63
	FAL	8.25±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.17
	HAL	6.66±[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]±0.03

Note: HSL, humic-like substance; FAL, fulvic acid-like; HAL, humic acid-like. Values are mean ± standard error.

4 Discussion

Continuous OM application influences soil organic matter levels and the quality of some or all of its pools (Cadisch and Giller, 2000). Many studies have shown that OMs positively alter soil environment and promote SOC storage (Liu et al., 2005; Purakayastha et al., 2008; Banger et al., 2010). Wang (2014) found that light organic carbon (LOC) and POC contents after straw application were significantly higher in semi-arid soil than in sub-humid soil, suggesting that OM effects on labile organic carbon may be greater in semi-arid soils. In this study, LC and RC contents increased significantly ($P<0.01$) after two years of continuous OM application compared with no OM (CK). Moreover, LC and RC contents were 3.2%-8.6% and 5.0%-9.4% higher in 2016 than in 2015, respectively, consistent with Wang (2014) who reported that SOC, LOC, and POC contents under straw treatment with plastic mulch were higher in 2010 than in 2009 and significantly higher than no-straw treatment.

OM application, OM sources, and decomposition degrees all affected SOC fractions under plastic film mulch (Li et al., 2009). Vanlauwe et al. (2005) indicated that short-term carbon dynamics were controlled by quality parameters of inputted OMs, such as lignin, N, and polyphenol contents. This finding was confirmed by Mandal et al. (2007) and Singh et al. (2009), who suggested that OM quality was an important factor for agricultural soil carbon changes beyond carbon input amount. In this study, carbon input was equivalent across OM treatments, so SOC fraction variations mainly depended on OM nature. Correlation analysis revealed that lignin and polyphenol contents in OMs played important roles in SOC and RC contents, consistent with Gentile et al. (2010). Puttaso et al. (2013) found that lignin and polyphenols were more resistant and difficult to decompose compared with cellulose and hemicellulose, thus benefiting SOC improvement. Similarly, Trinsoutrot et al. (2000) indicated that residues with higher lignin and polyphenol concentrations might be more stable as important SOC components through biochemical processes due to highly recalcitrant lignin. Moreover, this study found that the most important factors affecting SOC and RC contents were WOM, WHA, HSL, and HAL contents in OMs.

Decomposition rate is an important index for maintaining and improving soil organic matter distribution and fertility (Li et al., 2015). This study found OM decomposition rates followed the descending order CM > SM > MS > MR > FG > TL, with CM, SM, and MS showing obviously higher rates than MR, FG, and TL. Gao et al. (2010) and Liang et al. (2011) reported that water-soluble organic carbon (WOC) contents after animal manure application were higher than after straw application. In this study, LC contents after CM and SM applications were significantly higher than other OMs, followed by MS, while TL produced the lowest LC content. Similarly, LC/SOC ratios after CM and SM applications were higher, implying these treatments favored SOC mineralization and turnover. Moreover, OM decomposition rate was positively related to LC content and LC/SOC ratio. Therefore, CM and SM applications significantly increased LC contents and LC/SOC ratios mainly due to their higher decomposition rates. Conversely, SOC and RC contents after TL and MS applications were significantly higher than other OMs, with correspondingly higher RC/SOC ratios, implying TL and MS applications favored SOC storage. The higher RC and SOC contents under TL and MS treatments could be attributed to higher lignin/N ratios and lignin and polyphenol contents in TL and MS, which differs from Long et al. (2015) who found that pig manure treatment produced significantly higher SOC content than straw treatment in silt loam. This inconsistency may be attributed to different soil types and environments.

Wang et al. (2014) and Liu et al. (2014) studied maize straw decomposition rate in semi-arid dryland soil under plastic film mulch using nylon mesh bag methods and found that plastic film mulch promoted carbon mineralization. Therefore, OM application in semi-arid soils under long-term plastic film mulch conditions is necessary. This study showed that six OM types significantly increased SOC, LC, and RC contents. However, variations in LC and RC contents, LC/SOC ratio, and RC/SOC ratio differed significantly among the six OM treatments. For example, MS had a higher decomposition rate and the highest WOM, WHA, HSL, and HAL contents, with more lignin derivatives, WHA, and HAL polymers produced during decomposition. Thus, MS is recommended for use under plastic mulch and drip irrigation in semi-arid soils.

5 Conclusions

A two-year field experiment demonstrated that LC and RC contents increased significantly after continuous OM application. LC and RC contents were 3.2%-8.6% and 5.0%-9.4% higher in 2016 than in 2015, respectively. LC contents were significantly higher after CM and SM applications, followed by MS, while TL produced the lowest LC content. Additionally, LC/SOC ratios were significantly higher after CM and SM applications. SOC and RC contents were significantly higher after TL and MS applications, while CM and SM produced relatively lower values. RC/SOC ratios were also higher after TL and MS applications. In conclusion, applying MS to semi-arid soils under long-term plastic mulch and drip irrigation can improve both soil fertility and carbon sequestration.

Acknowledgements: This research was supported by the National Key R&D Program of China (2017YFD0201801) and the Research Foundation of the Science & Technology Agency of Jilin Province, China (20150203004NY).

References

Banger K, Toor G S, Biswas A, et al. 2010. Soil organic carbon fractions after 16-years of applications of fertilizers and organic manure in a Typic Rhodalfs in semi-arid tropics. Nutrient Cycling in Agroecosystems, 86(3): 391-399.

Cadisch G, Giller K E. 2000. Soil organic matter management: the role of residue quality in carbon sequestration and nitrogen supply. In: Rees R M, Ball B, Campbell C D, et al. Sustainable Management of Soil Organic Matter. Wallingford, UK: CAB International, 97-111.

Chen A Q, Fu B, Lu Y, et al. 2015. Exogenous organic materials applied to paddy field improving soil microbial biomass C, N and dissolved organic C, N. Transactions of the Chinese Society of Agricultural Engineering, 31(21): 160-167. (in Chinese)

Cookson W R, Abaye D A, Marschner P, et al. 2005. The contribution of soil organic matter fractions to carbon and nitrogen mineralization and microbial community size and structure. Soil Biology and Biochemistry, 37(9): 1726-1737.

Du Z L, Ren T S, Hu C S, et al. 2013. Soil aggregate stability and aggregate-associated carbon under different tillage systems in the North China plain. Journal of Integrative Agriculture, 12(11): 2114-2123.

Gao Z X, Zhou J B, Wang X, et al. 2010. Effects of different fertilizer treatments on content and characteristics of dissolved organic carbon in soil. Acta Pedologica Sinica, 47(1): 115-121. (in Chinese)

Gentile R, Vanlauwe B, Kavoo A, et al. 2010. Residue quality and N fertilizer do not influence aggregate stabilization of C and N in two tropical soils with contrasting texture. Nutrient Cycling in Agroecosystems, 88(1): 121-131.

Gougoulias C, Clark J M, Shaw L J. 2014. The role of soil microbes in the global carbon cycle: tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. Journal of the Science of Food and Agriculture, 94(12): 2362-2371.

Haubensak K A, Hart S C, Stark J M. 2002. Influences of chloroform exposure time and soil water content on C and N release in forest soils. Soil Biology and Biochemistry, 34(11): 1549-1562.

Haynes R J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. Advances in Agronomy, 85: 221-268.

Huygens D, Rütting T, Boeckx P, et al. 2007. Soil nitrogen conservation mechanisms in a pristine south Chilean Nothofagus forest ecosystem. Soil Biology and Biochemistry, 39(10): 2448-2458.

Jiang Y, Shi C Y, Wang Z Z, et al. 2014. Effects of plastic film mulching on arable layer soil temperature, moisture and yield of sweet potato. Chinese Journal of Eco-Agriculture, 22(6): 627-634. (in Chinese)

Knoblauch C, Maarifat A A, Pfeiffer E M, et al. 2011. Degradability of black carbon and its impact on trace gas fluxes and carbon turnover in paddy soils. Soil Biology and Biochemistry, 43(9): 1768-1778.

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677): 1623-1627.

Li H, Wang Z H, Wang X N, et al. 2007. Effects of cultivation types on yield formation and nitrogen accumulation and remobilization for winter wheat. Journal of Agro-Environment Science, 26(1): 369-374. (in Chinese)

Li L L, Wang Z H, Wang X N, et al. 2009. Effects of soil-surface mulching on organic carbon, inorganic carbon and light fraction organic carbon in dryland soil. Plant Nutrition and Fertilizer Science, 15(2): 478-483. (in Chinese)

Li X H, Guo H H, Zhu Z L, et al. 2016. Effects of different straw return modes on contents of soil organic carbon and fractions of soil active carbon. Transactions of the Chinese Society of Agricultural Engineering, 32(9): 130-135. (in Chinese)

Li S P, Cai Z C, Yang H, et al. 2009. Effects of long-term fertilization and plastic film covering on some soil fertility and microbial properties. Acta Ecologica Sinica, 29(5): 2489-2498. (in Chinese)

Li Z P, Liu M, Jiang C Y. 2015. Decomposition, accumulation and distribution of soil organic matter in typical red soil region of China. Soils, 47(2): 220-228. (in Chinese)

Liang Y, Han X Z, Song C, et al. 2011. Impacts of returning organic materials on soil labile organic carbon fractions redistribution of mollisol in northeast China. Scientia Agricultura Sinica, 44(17): 3565-3574. (in Chinese)

Liang Y. 2012. Effect of organic amendments application on dynamics, fractions and structural properties of soil organic matter in black soil. PhD Dissertation. Changchun: Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. (in Chinese)

Liu S W, Zhang Y J, Zong Y J, et al. 2016. Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis. Global Change Biology Bioenergy, 8(2): 392–406.

Liu X B, Liu J D, Xing B S, et al. 2005. Effects of long-term continuous cropping, tillage, and fertilization on soil organic carbon and nitrogen of black soils in China. Communications in Soil Science and Plant Analysis, 36(9–10): 1229–1239.

Liu X E, Li X G, Hai L, et al. 2014. Film-mulched ridge-furrow management increases maize productivity and sustains soil organic carbon in a dryland cropping system. Soil Science Society of America Journal, 78(4): 1434–1441.

Long P, Sui P, Gao W S, et al. 2015. Effects of agricultural organic wastes incorporation on soil organic carbon and microbial carbon. Journal of China Agricultural University, 20(3): 153-160. (in Chinese)

Loveland P, Webb J. 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil and Tillage Research, 70(1): 1–18.

Mandal B, Majumder B, Bandyopadhyay P K, et al. 2007. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India. Global Change Biology, 13(2): 357–369.

Manna M C, Swarup A, Wanjari R H, et al. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. Field Crops Research, 93(2–3): 303–315.

McLauchlan K K, Hobbie S E. 2004. Comparison of labile soil organic matter fractionation techniques. Soil Science Society of America Journal, 68(5): 1616–1625.

Meijboom F W, Hassink J, Van Noordwijk M. 1995. Density fractionation of soil macroorganic matter using silica suspensions. Soil Biology and Biochemistry, 27(8): 1109–1111.

Meng Q F, Yang J S, Yao R J, et al. 2013. Fertilization affects biomass production of Suaeda salsa and soil organic carbon pool in east coastal region of China. Journal of Integrative Agriculture, 12(9): 1659–1672.

Müller C, Stevens R J, Laughlin R J. 2004. A N15 tracing model to analyze N transformations in old grassland soil. Soil Biology and Biochemistry, 36(4): 619–632.

Nandwa S P. 2001. Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern

Africa. Nutrient Cycling in Agroecosystems, 61: 143-158.

Plaza-Bonilla D, Álvaro-Fuentes J, Cantero-Martínez C. 2014. Identifying soil organic carbon fractions sensitive to agricultural management practices. Soil and Tillage Research, 139: 19-22.

Purakayastha J, Rudrappa L, Singh D, et al. 2008. Long-term impact of fertilizers on soil organic carbon pools and sequestration rates in maize-wheat-cowpea cropping system. Geoderma, 144(1-2): 370-378.

Puttaso A, Vityakon P, Rasche F, et al. 2013. Does organic residue quality influence carbon retention in a tropical sandy soil? Soil Science Society of America Journal, 77(3): 1001-1011.

Schmidt M W I, Torn M S, Abiven S, et al. 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478(7367): 49-56.

Singh K P, Ghoshal N, Singh S. 2009. Soil carbon dioxide flux, carbon sequestration and crop productivity in a tropical dryland agroecosystem: influence of organic inputs of varying resource quality. Applied Soil Ecology, 42(3): 243-253.

Sparling G, Schipper L. 2004. Soil quality monitoring in New Zealand: trends and issues arising from a broad-scale survey. Agriculture, Ecosystems & Environment, 104(3): 545-552.

Trinsoutrot I, Recous S, Bentz B, et al. 2000. Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under nonlimiting nitrogen conditions. Soil Science Society of America Journal, 64(3): 918-926.

Troy S M, Lawlor P G, O' Flynn C J, et al. 2013. Impact of biochar addition to soil on greenhouse gas emissions following pig manure application. Soil Biology and Biochemistry, 60: 173-181.

Turkmen N, Sari F, Velioglu Y S. 2006. Effects of extraction solvents on concentration and antioxidant activity of black and black mate tea polyphenols determined by ferrous tartrate and Folin-Ciocalteu methods. Food Chemistry, 99(4): 835-841.

Van Soest P J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. Journal of the Association of Official Agricultural Chemists, 46(5): 829-835.

Vanlauwe B, Gachengo C, Shepherd K, et al. 2005. Laboratory validation of a resource quality-based conceptual framework for organic matter management. Soil Science Society of America Journal, 69(4): 1135-1145.

Walkley A, Black C A. 1934. Acid extractable Zn in soil in relation to the occurrence of Zn deficiency symptoms of corn: A method of analysis. Soil Science Society of America Journal, 12: 143-148.

Wang Y P. 2014. Effect of straw returning and plastic film mulching coupling on maize yield and the balance of organic matter in the Loess Plateau. PhD Dissertation. Lanzhou: Lanzhou University. (in Chinese)

Wang Y P, Li X G, Hai L, et al. 2014. Film fully-mulched ridge-furrow cropping affects soil biochemical properties and maize nutrient uptake in a rainfed semi-arid environment. Soil Science and Plant Nutrition, 60(4): 486–498.

Wu J G, Lü Y, Wang M H, et al. 2004. Study on decomposition of organic fertilizers by FTIR. Plant Nutrition and Fertilizer Science, 10(3): 259–266. (in Chinese)

Yin T, He W Q, Yan C R, et al. 2014. Effects of plastic mulching on surface of no-till straw mulching on soil water and temperature. Transactions of the Chinese Society of Agricultural Engineering, 30(19): 78–87. (in Chinese)

Yu W S, Li G H, Wang B S, et al. 2015. Component characteristics of soil labile and recalcitrant carbon under long-term different fertilization systems in eastern China. Plant Nutrition and Fertilizer Science, 21(3): 675–683. (in Chinese)

Zhang X B, Xu M G, Zhang W J, et al. 2011. Characteristics of CO2 emission and microbial biomass dynamics after adding various organic materials in red soil. Scientia Agricultura Sinica, 44(24): 5013–5020. (in Chinese)

Note: Figure translations are in progress. See original paper for figures.