Journal of Soils and Sediments (2020) 20:1920–1930
https://doi.org/10.1007/s11368-020-02589-0

SOILS, SEC 1 • SOIL ORGANIC MATTER DYNAMICS AND NUTRIENT CYCLING • RESEARCH ARTICLE

Assessment of soil aggregation properties after conversion from rice to greenhouse organic cultivation on SOC controlling mechanism

Lingying Xu[1,2,3] • Meiyan Wang[1] • Xinqiao Xie[4] • Xuezheng Shi[1] • Shengxiang Xu[1] • Weixia Sun[1] • Yijie Shi[1,2] • Quanbo Yu[1,2] • Jinhua Pan[1,2] • Xiangwei Li[4] • Yutian Tian[4] • Yuncong Zhu[4]

Received: 15 October 2019 / Accepted: 10 February 2020 / Published online: 2 March 2020

Abstract

Purpose Organic manure is beneficial for macro-aggregate formation and soil organic carbon (SOC), but how SOC change in aggregate fractions in time-series is still uncertain. Moreover, greenhouse systems converted from cereal fields quickly faced soil degradation. Thus, the role of organic manure here should be discussed. The main objectives of this study were to determine the change of SOC fractions in bulk soil and aggregation level affected by long-term organic manure application.

Materials and methods Using ^{13}C solid-state nuclear magnetic resonance (NMR) spectroscopy, we investigated the SOC and its fraction changes within bulk soil and aggregate fractions under 1-year, 9-year, and 14-year organic greenhouse vegetable cultivation, and we also analysed the soil properties of rice-wheat rotation (RWR) fields as the control. Soil aggregate samples were wet sieved into large macro-aggregates (> 2 mm), small macro-aggregates (2–0.25 mm), micro-aggregates (0.053–0.25 mm), and silt and clay particles (<0.053 mm).

Results and discussion The proportion of large macro-aggregates increased significantly ($P \leq 0.05$) from 1.68 to 7.76% during the 14-year organic cultivation period. Similar trends could also be found in SOC and its fractions. Specifically, the O-alkyl C increased fastest by 14.5 g kg^{-1} over these years, but its proportion decreased. The change in aggregate associated C was concentrated on large macro-aggregates and micro-aggregates. Pearson's correlation suggested that there was a non-significant relation between SOC and soil aggregation, while the soil aggregate associated C had a significantly positive relationship with SOC and its fraction amounts. However, the proportion of O-alkyl C was less; the aggregation associated C was higher.

Conclusions This study has shown the different effects of SOC fractions on soil aggregation and aggregate associated C in organic greenhouse vegetable fields. The stable C fractions might show contribution in soil aggregate associated C than active C fractions. It might improve our knowledge about how organic manure may influence soil aggregation by increasing SOC after a long-term greenhouse vegetable plantation.

Keywords Land-use conversion · Organic manure · Soil aggregation · Soil organic carbon · Aggregate associated carbon · ^{13}C solid-state NMR spectroscopy

Abbreviations

BD	bulk density
AN	available nitrogen
AP	available phosphorus
AK	available potassium
TN	total nitrogen

Responsible editor: Zucong Cai

✉ Meiyan Wang
mywang@issas.ac.cn

1 State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, People's Republic of China

2 University of the Chinese Academy of Sciences, Beijing 100049, People's Republic of China

3 Plant & Food Research, Canterbury Agriculture & Science Centre, Gerald St, Lincoln 7608, New Zealand

4 Hongta Tobacco Group Company Limited, Hongta Avenue, Yuxi, Yunnan 653100, People's Republic of China

TP	total phosphorus
TK	total potassium.
RWR	rice-wheat rotation plots
OGV1	one-year-old organic greenhouse vegetable plots
OGV9	nine-year-old organic greenhouse vegetable plots
OGV14	fourteen-year-old organic greenhouse vegetable plots

1 Introduction

Soil aggregates, which affects crop yield and quality, are considered as essential bases and units of soil structure (Bashir et al. 2016), and their distribution and stability are closely associated with other soil physical-chemical properties (Dorji et al. 2019). Generally, soil organic carbon (SOC) is one of the major factors involved in the formation of soil aggregates (Wang et al. 2018). The application of organic manure constitutes a typically sustainable agricultural practice to increase SOC contents (Naveed et al. 2013) and improve soil aeration (Wolf & Snyder 2003) in the short term period. However, the effects of organic manure on soil physical properties vary, although total SOC increase (Xu et al. 2018).

Organic manure is always recognized as sustainable agricultural practice and plays a vital role in the decrease of bulk density (BD) (Padbhushan et al. 2016) and macro-aggregate formation (Brar et al. 2013). A 9-year Indian field experiment suggested that the aggregate size distribution (> 0.25 mm) in farmyard manure was higher than the 100% NPK treatment (Padbhushan et al. 2016). Similar results were obtained by Mangalassery et al. (2019), they found that the proportion of macro-aggregates (> 0.25 mm) and mean weight diameter (MWD) increased under after 5-year organic manure application. Moreover, Ghosh et al. (2019b) proved that organic manure in intensive agricultural systems could protect soil from physical degradation after an 11-year study in the European Union. Plaza-Bonilla et al. (2013) reported that organic manure slightly increased water-stable macro-aggregates compared with chemical fertilization but caused no differences in SOC or macro-aggregate C concentrations. However, most of the research focused on the comparison among different fertilizers (Ghosh et al. 2016, Guo et al. 2018, Hernandez et al. 2017, Wang et al. 2017), the effects in different time series were always ignored. Besides, Xu et al. (2018) and Papadopoulos et al. (2009) confirmed that organic manure played a stronger positive effect on soil structure improvement in the earlier period, and the effects might lessen with time. Overall, organic manure could enhance soil physical quality (Mikha et al. 2015, Williams et al. 2017), but the role of organic manure in time scale has still not well realized.

It is essential to analyse the change of SOC to evaluate the effects of organic manure on soil aggregation characteristics (Mi et al. 2018). SOC is the primary source of crop nutrients and could improve the water holding capacity and aeration of soil (Wolf & Snyder 2003). Organic manure is beneficial to SOC sequestration (Hu et al. 2018, Huang et al. 2010). For example, Cai et al. (2016) indicated that long-term organic manure applications significantly increased the SOC within both bulk soil and particle size fractions. The research of Weyers et al. (2018) showed that organic manure had a positive impact on maintaining SOC over time compared with the chemical fertilization. The consistent conclusion has been obtained by Jiang et al. (2018). Besides, SOC fractions such as labile carbon, hot water-soluble carbon, particulate organic C (Chaudhary et al. 2017, Pritchett et al. 2011), are more sensitive to reflect the soil quality than total SOC, and obtained attention widely by researchers (Plaza-Bonilla et al. 2013). Li et al. (2018b) found that a 26-year organic manure application could significantly increase total SOC amount and labile organic C fractions compared with chemical fertilization. In addition, a 15-year experiment suggested that labile fractions of SOC were early indexes of SOC on a short-term basis and that different organic manures played different roles in long-term C sequestration (Chaudhary et al. 2017).

In recent years, a ^{13}C solid-state nuclear magnetic resonance (NMR) spectroscopy has widely applied in the soil science research as a non-destructive technique (Ghosh et al. 2019a). Shrestha et al. (2015) found that farmyard manure may contribute to fertility loss by evaluating SOC quantity and quality with the ^{13}C solid-state NMR spectroscopy under long-term crop and management practices in Norway. A 34-year fertilization experiment suggested organic manure increased the levels of alkyl C and aromatic C but decreased O-alkyl C in Vertisols. However, Li et al. (2018a) believed that the organic manure treatment had a higher aromatic C–O and OCH_3 and lower alkyl C and OCH abundance in a Calcaric Fluvisol. The different soil types might cause the difference of SOC fractions. Thus, more evidence is required to discuss the change of SOC fractions with organic manure.

Besides, the mechanism between soil structure and SOC has always been referred in organic manure experiments (Abid & Lal 2008, Jensen et al. 2019, Naveed et al. 2014). Generally, SOC could contribute to the stabilization of macro-aggregates (Jiang et al. 2018, Somasundaram et al. 2017, Zheng et al. 2016). However, as a group of complexes, the SOC fractions affecting the soil aggregation should be considered. With the development of technology, the research on SOC fractions combined with soil aggregation through some non-destructive methods has obtained attention widely. Sarker et al. (2018) suggested that the high proportion of aromatic carbons hampered soil aggregation. Besides, Mizuta et al. (2015) found that soil aggregate formation and stability were induced by polysaccharides. Although there has existed an extensive knowledge about the mechanisms of soil aggregation controlled by SOC (Regelink et al. 2015), the relation between soil structure and SOC dynamics has still not well understood (Blanco-Canqui & Lal 2004).

Therefore, the objectives of this study were: (1) to evaluate the change of soil aggregation distribution; (2) to analyse the SOC and its fractions in both bulk soil and aggregate level; and (3) to preliminarily establish the relation between soil aggregation properties and SOC characteristics. To solve it, we chose the organic greenhouse vegetable fields converted from rice-wheat rotation (RWR) plots for different durations (one year, nine years, and fourteen years). Greenhouse converted from RWR easily faced soil structure degradation (Rodrigo-Comino et al. 2018), so the impacts of organic manure should be distinguished (Xu et al. 2019, Zikeli et al. 2017). It might further improve our knowledge of how SOC fractions affect soil aggregation in response to applications of long-term organic manure, which has a theoretical significance for sustainable agriculture.

2 Methods and materials

2.1 Site description

The research site is located in the urban area of Nanjing city (latitude 31°52’ N, longitude 118°42′ E), Jiangsu Province, Southeast China. The annual mean temperature and precipitation are 15.7 °C and 1072.9 mm, respectively. The parent material of the agricultural soil is Quaternary loess, and the main soil type is Anthrosol (Inceptisol) (IUSS-WRB 2014). The soil is a silty loam, and the main crop system before our research was a RWR system. All of these vegetable plots are managed by a local company. The main crops include leaf vegetable species such as cabbage (*Brassica oleracea var. capitata*) and spinach (*Spinacia oleracea*) (Chen et al. 2014). The amount of organic manure added to the vegetable fields was approximately 14,000 kg ha^{-1} during a long growth period (one or two crops per year) and approximately 7500 kg ha^{-1} during a short growth period (more than two crops per year) before vegetable plantations. The total nutrients ($N + P_2O_5 + K_2O$) was up to 10%, and the organic matter was more than 45% in this manure.

There were four treatments in our research, which were one-year-old organic greenhouse vegetable plots (OGV1), nine-year-old organic greenhouse vegetable plots (OGV9), and fourteen-year-old organic greenhouse vegetable plots (OGV14). Besides, we chose the RWR fields near the organic greenhouse fields as the control for this study. All organic greenhouse vegetable plots converted from RWR fields experienced approximately three-year-long fallow periods before the first time of vegetable cultivation.

2.2 Soil sampling and pre-processing

Soil samples were collected from the top layer (0–15 cm) in the summer of 2016 after the vegetable and cereal harvest. Three disturbed soil samples were randomly sampled in each treatment. For each treatment, three intact cores approximately 50 mm in diameter and 50 mm in length were extracted, and the cutting ring method was used to determine the BD in the laboratory (Githinji 2014). Each disturbed sample was gently broken apart along natural breakpoints and then passed through a 10 mm sieve. Stones and plant roots were removed, after which the remaining soil was allowed to dry naturally. Each sample was divided into two parts: one part was used for the determination of the aggregate size distribution, and the other part was used for the evaluation of bulk soil. Disturbed soil samples were also taken to measure soil basic properties (e.g., pH, SOC, soil total nutrients, and available nutrients) according to the methods of Lu (2000).

2.3 Aggregate separation

The soil aggregates were separated by wet sieving according to previously described methods (Kemper & Rosenau 1986, Plaza-Bonilla et al. 2013); sieving was performed with a series of three sieves that separated the samples into four different soil fractions: large macro-aggregates (> 2 mm), small macro-aggregates (0.25–2 mm), micro-aggregates (0.053–0.25 mm), and silt and clay particles (< 0.053 mm). Soil particles that passed through the sieves were dried (40 °C) and weighed. The MWD, geometric mean diameter (GMD), mean weight-specific surface area (MWSSA), and fractal dimension (D) were determined according to Cui et al. (2019) and Huang et al. (2017). It indicated the stability of soil aggregates. When the MWD and GWD are relatively high, the MWSSA and D are relatively low, and the aggregate structure is strong. Samples were collected to determine the SOC, while the remaining samples were mixed within their respective class and then passed through a 100 mesh sieve for SOC fraction analysis.

2.4 ^{13}C NMR spectroscopy

The soil samples were pre-processed for SOC fraction analysis according to the methods of Skjemstad et al. (1994). A five *g* soil sample was placed into a 100 ml centrifuge tube to which 50 ml of 2% (*v*/v) hydrofluoric acid (HF) was added and mixed. The mixture was shaken for 2 h and then centrifuged at 3600 rpm for 10 min, after which the supernatant was discarded. This process was repeated 5 times, and the shaking time was increased to 16 h in two additional replications. The residual soil sample was finally washed with distilled water three times, dried at 40 °C, and passed through a 100 mesh sieve for further analysis.

A ^{13}C cross-polarization/total sideband suppression (CP/TOSS) and CP/TOSS with dipolar dephasing experiments were performed via a Bruker Ultra Shield Plus 400 MHz wide-bore spectrometer for ^{13}C with 4 mm sample rotors. The experiments were conducted at a spinning speed of 10 kHz and with both a connection time of 2 s and a recycle delay of 2 s. Following the methods of previous studies (Mao et al. 2008, Mathers et al. 2007), the ^{13}C NMR signals were categorized as follows: alkyl C (δ = 0~45 ppm), O-alkyl C (δ = 45~110 ppm), aromatic C (δ = 110~165 ppm), and carbonyl C (δ = 165~220 ppm). All of these proportions were obtained via Mest ReNova 9.0.1 (Mestre-lab Research, 2014). The SOC amount in each fraction was determined by multiplying the proportion of each SOC fraction by the total SOC (Zhang et al. 2017).

2.5 Statistical analysis

All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 19.0 (SPSS Inc., Chicago, IL) and Excel 2013. The mean values were tested via the least significant difference (LSD) (Duncan's LSD) method at the $P \leq 0.05$ level of statistical significance. The interactions among soil properties were analysed by Pearson's correlation. The statistical significance of the Pearson's correlation coefficient was determined at the $p = 0.05$ and $p = 0.01$ levels.

3 Results

3.1 Variation of basic soil properties

The trends of basic soil properties differed significantly ($P \leq 0.05$) over the 14-year organic greenhouse plantation converted from RWR fields except for the pH value (Table 1). For example, the BDs in four treatments were as follows: OGV1 (1.40 g cm^{-3}) > OGV9 (1.14 g cm^{-3}) > RWR (1.09 g cm^{-3}) > OGV14 (1.02 g cm^{-3}). In other words, the BD decreased with the long-term organic manure application. Besides, the BD of RWR furtherly confirmed that long-term organic manure application could restore the soil structure and return to the original background value compared with OGV14. Besides, compared with soil nutrients, there was no significant ($P > 0.05$) difference in available nutrients between RWR and OGV1 plots. While the soil available nutrients increased obviously during 14-year organic greenhouse plantation. These results were similar to the figure for soil total nutrients. Thus, better soil structure and more soil nutrients accumulation were found in long-term organic greenhouse systems.

3.2 Aggregate distribution and stability

The distribution patterns in the proportions of soil aggregates were similar among four treatments (Fig. 1), and the percentage of micro-aggregates was the highest among these aggregations. However, there was an obvious change of these aggregates during the 14-year organic greenhouse cultivation. For example, the proportion of large macro-aggregates (> 2 mm) accounted for 51.3%, 16.8%, 28.3%, and 37.9% of the aggregates in RWR, OGV1, OGV9, and OGV14 plots, respectively. A similar trend could be obtained in the small macro-aggregates (0.25–2 mm). However, the trend was different in the micro-aggregates (0.053–0.25 mm) and silt and clay (< 0.053 mm). The data in Table 2 also indicated that the MWD and GWD significantly ($P \leq 0.05$) increased but that the D and MWSSA decreased in response to long-term organic manure. Overall, the aggregation stability improved, and the proportion of macro-aggregation (> 0.25 mm) increased after land-use conversion. It might be caused by the continuous organic manure application.

3.3 SOC in bulk soil and aggregates

In our study, the SOC in bulk soils differed significantly ($P \leq 0.05$) during the 14-year organic greenhouse plantation (Fig. 2). For example, the OGV14 plots (41.5 g kg^{-1}) presented the highest SOC content, with five times greater than the SOC content in the OGV1 plots (6.7 g kg^{-1}). The difference of SOC in the RWR and OGV1 plots was because of the conversion period, during which the soil in the plough layer was brought to the surface. To sum up, organic manure could help the SOC stock after land-use conversion.

Besides, the SOC at different aggregate factions showed various tendencies over the 14-year organic cultivation (Fig. 2). The SOC within large macro-aggregates (> 2 mm) increased most rapidly (from 7.06 g kg^{-1} to 43.69 g kg^{-1}), followed by that within the micro-aggregates (0.053–0.25 mm) and small macro-aggregates (0.25–2 mm). The SOC within the silt and clay particle (< 0.053 mm) fractions remained stable. As expected, our results indicated a clear difference in SOC within aggregate size fractions in response to organic manure. In conclusion, organic manure played a positive role in SOC, but the effects in different aggregates were different.

3.4 SOC fractions in bulk soil and aggregates

The SOC fractions in bulk soil increased significantly ($P \leq 0.05$) with continual organic manure input in the organic greenhouse vegetable plots converted from RWR plots (Fig. 3). For example, the amount of O-alkyl C increased as follows: OGV1 (3.5 g kg^{-1}) < OGV9 (14.6 g kg^{-1}) < OGV14 (17.9 g kg^{-1}); a similar trend was found for alkyl C, aromatic

Table 1 Indices of soil basic properties in the long-term organic greenhouse fields converted from rice-wheat rotation ($n = 3$)

Treatments	RWR	OGV1	OGV9	OGV14
BD (g cm^{-3})	1.09 ± 0.04 a	1.40 ± 0.02 b	1.14 ± 0.02 c	1.02 ± 0.03 d
pH	5.42 ± 0.32 a	6.01 ± 0.11 a	5.65 ± 0.18 a	5.49 ± 0.11 a
AN (mg mg^{-1})	127.40 ± 28.25 a	120.05 ± 9.80 a	286.65 ± 11.23 b	289.10 ± 6.48 b
AP (mg mg^{-1})	24.90 ± 10.60 a	11.67 ± 3.29 a	136.66 ± 11.16 b	194.04 ± 6.82 c
AK (mg mg^{-1})	65.00 ± 4.33 a	107.50 ± 9.46 a	499.17 ± 173.93 b	800.00 ± 76.03 b
TN (g kg^{-1})	1.51 ± 0.21 a	0.97 ± 0.07 b	3.19 ± 0.05 c	3.90 ± 0.02 d
TP (g kg^{-1})	0.79 ± 0.09 a	0.56 ± 0.02 ab	1.16 ± 0.11 b	1.71 ± 0.22 c
TK (g kg^{-1})	12.54 ± 0.29 a	18.39 ± 0.42 b	21.38 ± 0.70 bc	22.71 ± 2.13 c

Notes: the different letters indicate significant differences among the four treatments (Duncan's post hoc test at $p < 0.05$). The error bars are the standard errors

C, and carbonyl C. Besides, the increase in SOC fractions under long-term organic greenhouse vegetable plots were concentrated within macro-aggregate (> 0.25 mm) and micro-aggregate (0.053–0.25 mm) fractions (Fig. 4). For example, the O-alkyl C in large macro-aggregate (> 2 mm) obviously increased from 2.21 to 14.15 g kg^{-1} in the fourteen-year organic plantation. Among that, O-alkyl C was mostly affected by organic manure application in both bulk soil and aggregate level. Even that, the proportion of the O-alkyl C in bulk soil tended to be opposite, decreasing from 52.1 to 43.21% under organic cultivation (Fig. 5). However, the proportions of the aromatic C and carbonyl C in bulk soil increased by 5.77% and 3.44%, respectively (Fig. 5). In addition, the SOC fractions within silt and clay (< 0.053 mm) remained relatively stable throughout the entire study. Overall, organic manure could help to increase all the SOC fractions in both bulk soil and aggregate level; the change in aggregation was concentrated on within macro-aggregates (> 0.25 mm) and micro-aggregates (0.053–0.25 mm), and O-alkyl C increased most rapidly throughout the whole organic cultivation.

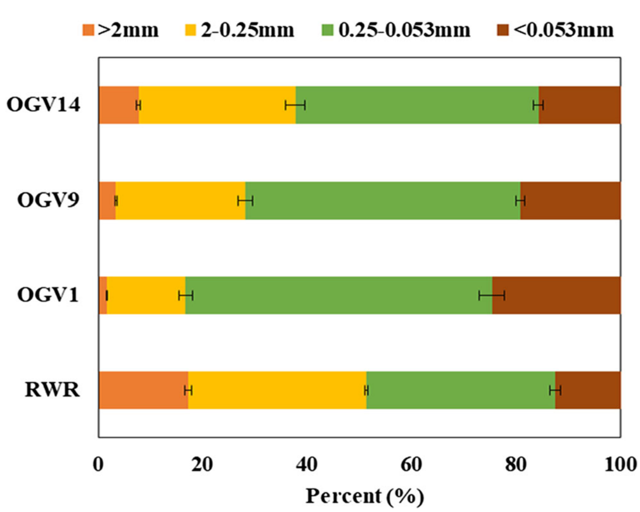

Fig. 1 Changes in aggregate size distribution under different treatments ($n = 3$). The error bars illustrate the standard errors of the means (±). RWR, rice-wheat rotation plots; OGV1, one-year-old organic greenhouse vegetable plots; OGV9, nine-year-old organic greenhouse vegetable plots; OGV14, fourteen-year-old organic greenhouse vegetable plots

3.5 Pearson's correlations

The effects of soil aggregation properties on organic manure are complex, and we analysed the main factors in this study through Pearson's correlation. The results suggested that there was a significantly positive ($P \leq 0.05$) relationship between BD and micro-aggregates (0.25–0.053 mm) opposite with the macro-aggregates (Table 3). Besides, there was no significant relation between the soil aggregate distribution and soil fertility indexes (e.g., soil available nutrients, soil total nutrients, and SOC) except total potassium (TK). However, the soil aggregate associated C had a significant relationship with these indexes, especially the SOC in large macro-aggregates (> 2 mm) and micro-aggregates (0.25–0.053 mm). Similar results were also obtained in Table 4; the soil aggregate-associated C showed a more obvious relationship with SOC fractions compared with soil aggregation. On the one hand, the increase of these SOC fractions could be beneficial to soil aggregate-associated C especially in large macro-aggregates (> 2 mm) and micro-aggregates (0.25–0.053 mm). On the other hand, the proportion of O-alkyl C had a significantly negative ($P \leq 0.05$) effect on soil aggregate-associated C. On the contrary, the proportion of aromatic C and carbonyl C played a positive role on it. Above all, BD had a close relation with soil aggregation, and SOC and its fractions were related to soil aggregate-associated C. The proportion of O-alkyl C were less, the aggregate-associated C increased more.

4 Discussion

4.1 Effects of organic manure on soil aggregation and aggregate associated C

The distribution of soil aggregates reflects the soil physical properties and soil moisture supply (Wang et al. 2015). The

Table 2 Indices of soil aggregate characteristics in long-term organic greenhouse fields converted from rice-wheat rotation ($n = 3$)

Treatments	RWR	OGV1	OGV9	OGV14
MWD (mm)	1.47 ± 0.06 a	0.36 ± 0.03 b	0.56 ± 0.04 c	0.88 ± 0.03 d
GWD (mm)	0.46 ± 0.01 a	0.14 ± 0.01 b	0.20 ± 0.02 b	0.28 ± 0.03 c
D	2.74 ± 0.02 a	2.86 ± 0.03 b	2.82 ± 0.03 ab	2.78 ± 0.03 ab
MWSSA ($cm^2\ g^{-1}$)	16.77 ± 0.91 a	30.06 ± 3.44 b	24.71 ± 2.21 b	20.93 ± 2.04 c

Notes: the different letters indicate significant differences among the four treatments (Duncan's post hoc test at $p < 0.05$). The error bars are the standard errors

proportion of macro-aggregates is higher; the soil structure is better (Zou et al. 2018). In our research, organic manure could increase the macro-aggregation (>0.25 mm) and improve soil aggregate stability (an increase of MWD and GWD values, decrease of D and MWSSA) (Fig. 1). Consistent conclusions were also obtained by prior studies in the comparisons of organic manure and chemical fertilizer, as well as the change of the different amount of the organic manure (Udom et al. 2016, Zhou et al. 2016). Guo et al. (2019a) also found the soil aggregate stability increased after organic manure application in southern China. Besides, Wang et al. (2014) investigated that vegetable fields converted from paddies over 20 years, and the results showed that 14.01% of water-stable macro-aggregates were broken into the micro-aggregates after the land-use conversion. Haghighi et al. (2010) also found the MWD in the pasture was higher than dryland framing. It showed that intensive land-use conversion might lead to the degradation of soil macro-aggregation. Compared with our results, we could find that the organic manure played a significantly ($P \leq 0.05$) positive role in the soil macro-aggregate formation (Fig. 1).

Besides, the soil aggregate associated C presented an obvious change during the 14-year organic plantation. The SOC within both large macro-aggregates (> 0.25 mm) and micro-aggregates (0.053–0.25 mm) is strongly affected by organic manure (Fig. 2). SOC was the lowest within silt and clay (< 0.053 mm) size fractions. Similarly, E et al. (2012) noted that the SOC of aggregates was generally affected by organic manure, and that the magnitude of SOC increases was the greatest for large macro-aggregates. Bashir et al. (2016) also reported that the SOC within large macro-aggregates (2–8 mm) and micro-aggregates (0.05–0.25 mm) was the greatest in response to applications of 1% organic manure (the highest level in their study) in dryland under fallow-wheat rotation for two years. While, Xie et al. (2015) investigated the SOC in aggregate fractions in the long-term experiment of loess soil, and the results showed that fertilization did not affect the SOC in all aggregates compared with no nutrient input under dryland farming condition. Mangalassery et al. (2019) found the organic amendments increased SOC in all aggregate fractions in a weathered tropical soil. The difference could be mainly attributed to differences in soil types and climate conditions. Overall, continual organic manure input can increase fresh soil C contents, accelerate SOC turnover, and enhance

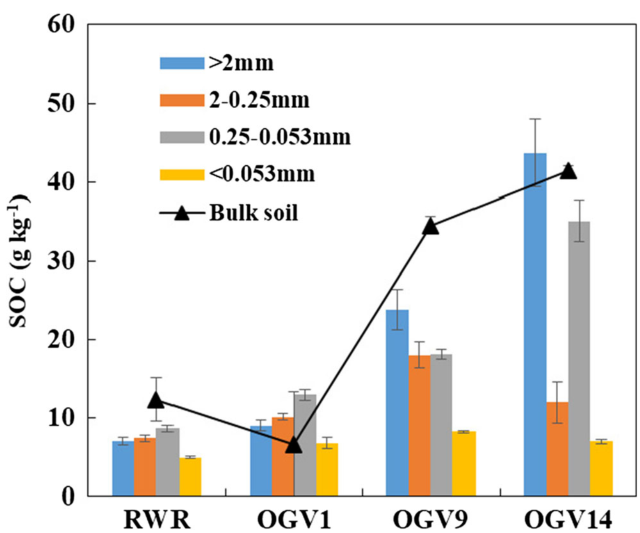

Fig. 2 Changes in the SOC within bulk soil and water-stable aggregate fractions under different treatments ($n = 3$). The error bars illustrate the standard errors of the means (±). RWR, rice-wheat rotation plots; OGV1, one-year-old organic greenhouse vegetable plots; OGV9, nine-year-old organic greenhouse vegetable plots; OGV14, fourteen-year-old organic greenhouse vegetable plots

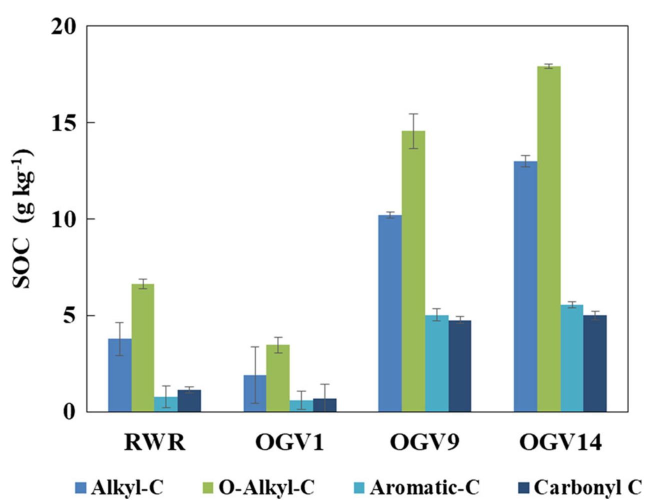

Fig. 3 Mean SOC fractions under different treatments ($n = 3$). The error bars illustrate the standard errors of the means (±). RWR, rice-wheat rotation plots; OGV1, one-year-old organic greenhouse vegetable plots; OGV9, nine-year-old organic greenhouse vegetable plots; OGV14, fourteen-year-old organic greenhouse vegetable plots

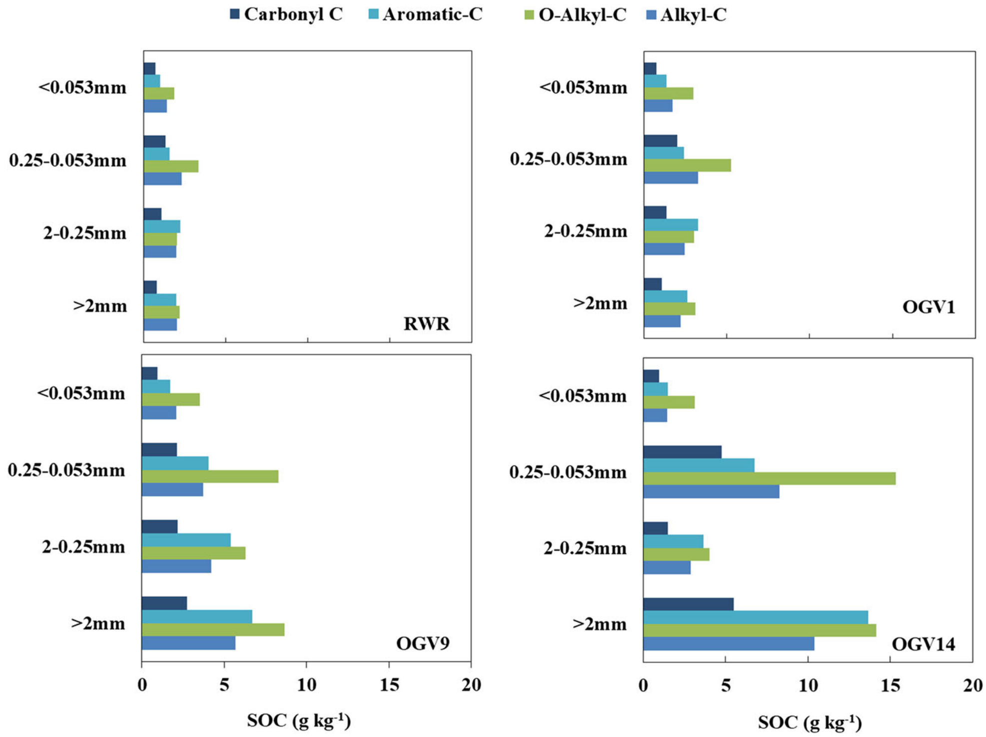

Fig. 4 SOC fractions within different water-stable aggregates under different treatments. RWR, rice-wheat rotation plots; OGV1, one-year-old organic greenhouse vegetable plots; OGV9, nine-year-old organic greenhouse vegetable plots; OGV14, fourteen-year-old organic greenhouse vegetable plots

macro-aggregate formation (Jiang et al. 2015). It also played a positive role in macro-aggregate-associated C, as noted by Bronick and Lal (2005).

4.2 Benefits of organic manure on SOC fractions

The effect of long-term organic manure on SOC fractions is a complex and dynamic process. Among all the fractions, The O-alkyl C increased most rapidly throughout the whole organic cultivation (Fig. 3). O-alkyl C is the most readily available C source for microorganisms and consists of polysaccharides and cellulose, which are preferentially decomposed (Baldock et al. 1992). Plenty of organic materials input increased O-alky C following the continuous organic manure application. Meantime, the proportion of O-alkyl C decreased significantly ($P \leq 0.05$) and remained stable after nine years of organic cultivation in contrast to that of alkyl C and aromatic C (Fig. 5). Generally, alkyl C and aromatic C are hydrophobic compounds, which are difficult to decompose (Guo et al. 2019b). In other words, the active SOC fractions increased readily, but compared with that in the original period, the composition of SOC tended to become more stable in response to applications of organic manure, which is consistent with the results of Preston et al. (2009). Moreover, the O-alkyl C within large macro-aggregates (> 2 mm) increased most rapidly during the first nine-year cultivation period; thereafter, it increased within both large macro-aggregates (>2 mm) and micro-aggregates (0.053–0.25 mm) (Fig. 4). The amount and proportion of aromatic C within large macro-aggregates (> 2 mm) was greater in the 14-year greenhouse plots than in the other plots, suggesting that the accumulated SOC became aromatic and stable over time (Fig. 4).

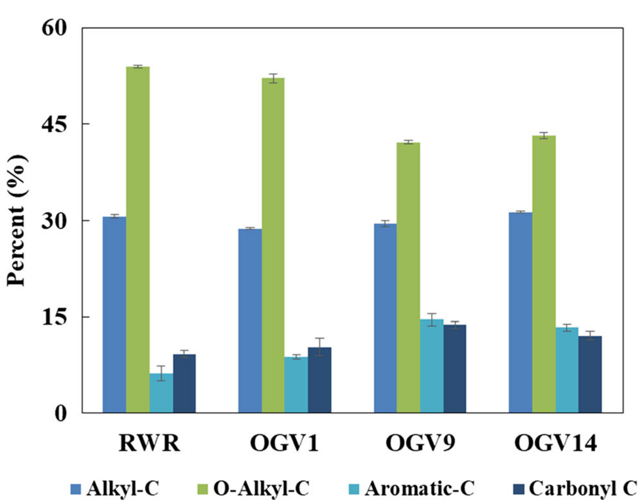

Fig. 5 Mean percentages of SOC fractions under different treatments ($n = 3$). The error bars illustrate the standard errors of the means (±). RWR, rice-wheat rotation plots; OGV1, one-year-old organic greenhouse vegetable plots; OGV9, nine-year-old organic greenhouse vegetable plots; OGV14, fourteen-year-old organic greenhouse vegetable plots

We speculated that the role of long-term organic manure on SOC fractions could be divided into two parts: one mainly involves the increase of the active C and soil

Table 3 Pearson's correlation between soil basic characteristics and soil aggregation parameters (*n* = 12)

	BD	AN	AP	AK	TN	TP	TK	SOC
Soil aggregation								
> 2 mm	−0.57	−0.24	−0.18	−0.21	−0.09	−0.03	**−0.67***	−0.12
2-0.25 mm	**−0.80****	0.22	0.33	0.24	0.35	0.41	−0.20	0.34
0.25–0.053 mm	**0.69****	0.06	−0.03	0.09	−0.08	−0.16	0.42	−0.04
< 0.053 mm	0.56	−0.13	−0.20	−0.22	−0.23	−0.25	0.30	−0.24
Soil aggregate associated carbon								
> 2 mm	−0.56	**0.81****	**0.93****	**0.86****	**0.90****	**0.91****	**0.79****	**0.88****
2-0.25 mm	−0.13	**0.68***	0.50	0.53	0.15	0.15	0.45	0.56
0.25–0.053 mm	−0.46	**0.76****	**0.87****	**0.89****	**0.83****	**0.83****	**0.74****	**0.82****
< 0.053 mm	0.06	**0.61***	0.52	0.51	0.50	0.35	**0.79****	0.52

Notes: bold values represent a significant correlation between the indexes

*means $P \le .05$ with Duncan's post hoc test

**means $P \le .01$ with Duncan's post hoc test

fertility improvement, and the other includes C sequestration. The effect of organic manure on SOC fractions still has been debated; some research found that farmyard manure applications can increase the proportion of alkyl C and aromatic C but decrease the proportion of O-alkyl C (Guo et al. 2019b), whereas another long-term experiment suggested that compost applications can increase the proportion of alkyl C and O-alkyl C (Lima et al. 2009). The difference might be attributed to the different kinds of organic manure materials. For example, the proportion of O-alkyl C in straw is approximately 70% (Mahieu et al. 1999), but it is nearly 30% within pig manure (Zhang et al. 2013). Overall, the organic manure could help the SOC fraction stock variously depending on the different kinds of the manure.

4.3 Interactions among soil aggregation characteristics and SOC fraction parameters

The increase of SOC could promote the macro-aggregate formation (Plaza-Bonilla et al. 2013, Sui et al. 2012, Trakooyingcharoen et al. 2012, Zhao et al. 2018). In our research, the SOC and its fractions did not have a significant ($P > 0.05$) relation with soil aggregation, but it affected soil aggregate associated C (Table 4). In other words, the effects of SOC on soil aggregation might promote the turnover of SOC in the aggregate size factions to format the soil aggregation. Besides, SOC played a significantly ($P \le 0.05$) positive role in soil aggregate-C in macro-aggregates (> 2 mm) and micro-aggregates (0.25–0.053 mm), consistent with the results from Bronick and Lal (2005) and Udom et al. (2016). Similarly, the

Table 4 Pearson's correlation between SOC fractions and soil aggregation characteristics (n = 12)

	Alkyl C (P)	O-alkyl C (P)	Aromatic C (P)	Carbonyl C (P)	Alkyl C (A)	O-alkyl C (A)	Aromatic C (A)	Carbonyl C (A)
Soil aggregation								
> 2 mm	0.49	0.43	−0.57	−0.52	−0.10	−0.06	−0.26	−0.21
2–0.25 mm	**0.69***	0.00	−0.15	−0.22	0.36	0.41	0.19	0.23
0.25–0.053 mm	−0.52	−0.27	0.41	0.39	−0.06	−0.10	0.09	0.04
< 0.053 mm	**−0.59***	−0.03	0.15	0.23	−0.27	−0.31	−0.12	−0.14
Soil aggregate associated carbon								
> 2 mm	0.46	**−0.82****	**0.75****	**0.62***	**0.90****	**0.86****	**0.87****	**0.84****
2-0.25 mm	−0.22	**−0.71***	**0.77****	**0.75****	0.52	0.53	**0.65***	**0.63***
0.25-0.053 mm	0.47	**−0.76****	**0.70***	0.53	**0.85****	**0.80****	**0.81****	**0.79****
< 0.053 mm	−0.19	**−0.75****	**0.78****	**0.81****	0.50	0.46	**0.62***	**0.61***

Notes: "P" presents the proportion of SOC fractions, "A" represents the amount of SOC fractions. Bold values represent a significant correlation between the indexes

*means $P \le .05$ with Duncan's post hoc test

**means $P \le .01$ with Duncan's post hoc test previous research also suggested that SOC was stabilized in both macro-aggregates (> 0.25 mm) and micro-aggregates (0.25–0.063 mm), and the physical-chemical protection of SOC was the key aspect to maintain soil C stocks (Garcia-Franco et al. 2015).

According to the role of SOC fractions, all SOC fractions amount had a significantly ($P \leq 0.05$) positive role on soil aggregate associated C, consistent with the relation between total SOC and soil aggregate associated C. Pulido-Moncada et al. (2018) found that there were significant associations between aggregate stability and SOC (0.79**), light fraction (0.69 **) and heavy fraction (0.70**). It meant that all SOC fractions stock could improve soil aggregate associated C, while, the level of the effects was different. With regard to the proportion of SOC fractions, the low proportion of O-alkyl C could accumulate soil aggregate associated C, opposite to the results of aromatic C and carbonyl C (Table 4). O-alkyl C is always recognized as the active C fractions, which is easily affected by external conditions (Erhagen et al. 2013). In other words, stable C fractions (e.g., aromatic C and carbonyl C) played a more obvious positive role on soil aggregate associated C rather than active C fractions. However, the research of Sarker et al. (2018) suggested O-alkyl C was positively associated with the aggregation index, but the aromatic fractions showed an opposite pattern. The difference might be due to the experiment time. Sarker et al. (2018) were concentrated on the short term observation over the 300 days of incubation, and the effects of aromatic C fractions could not play a role in this period. Overall, there was a close relation between SOC fractions and aggregation associated C, and the stable C fraction might play a more important role during the long-term organic manure application.

5 Conclusions

This study analysed the aggregation and SOC characteristics in response to long-term organic manure applications. The results suggested that both macro-aggregates and SOC and its fractions increased under fourteen years of organic cultivation. There was the most rapid increase in O-alkyl C during the organic greenhouse vegetable plantation, but its proportion decreased and then kept stable over time opposite to alkyl C and aromatic C. The change of SOC in aggregate sizes was mostly concentrated on large macro-aggregates (> 2 mm) and micro-aggregates (0.25–0.053 mm), the change in silt and clay (< 0.053 mm) fractions was little. Besides, the correlation between soil aggregation characteristics and other properties were analysed. It suggested that all soil fertilizer indexes did not have a significant ($P > 0.05$) relation with soil aggregation distribution, but it had a close relation with soil aggregate associated C. All of these soil fractions amounts could increase soil aggregate associated C stock, but the proportion of aromatic C and carbonyl C played a more positive role than O-alkyl C. It might improve our knowledge on how organic manure may influence soil aggregation by increasing SOC after long-term greenhouse vegetable plantation. Consequently, it has a theoretical significance for sustainable agricultural practices.

Funding information This research was supported by the National Key Research and Development Program of China (2018YFC1800201), the National Natural Science Foundation of China (Nos. 41571209 and 41401240), and the Technology Project of Hongta Tobacco Group Company Limited (S-6019001).

References

Abid M, Lal R (2008) Tillage and drainage impact on soil quality: I. aggregate stability, carbon and nitrogen pools. Soil Tillage Res 100:89–98

Baldock JA, Oades JM, Waters AG, Peng X, Vassallo AM, Wilson MA (1992) Aspects of the chemical structure of soil organic materials as revealed by solid-state 13C NMR spectroscopy. Biogeochemistry 16:1–42

Bashir K, Ali S, Ijaz SS, Ahmad I (2016) Effect of organic amendments on distribution, stability and carbon concentration of soil aggregates. Pak J Agric Sci 53:955–961

Blanco-Canqui H, Lal R (2004) Mechanisms of carbon sequestration in soil aggregates. Crit Rev Plant Sci 23:481–504

Brar B, Singh K, Dheri G (2013) Carbon sequestration and soil carbon pools in a rice–wheat cropping system: effect of long-term use of inorganic fertilizers and organic manure. Soil Tillage Res 128:30–36

Bronick CJ, Lal R (2005) Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in northeastern Ohio, USA. Soil Tillage Res 81:239–252

Cai A, Xu H, Shao X, Zhu P, Zhang W, Xu M, Murphy DV (2016) Carbon and nitrogen mineralization in relation to soil particle-size fractions after 32 years of chemical and manure application in a continuous maize cropping system. PLoS One 11:e0152521

Chaudhary S, Dheri GS, Brar BS (2017) Long-term effects of NPK fertilizers and organic manures on carbon stabilization and management index under rice-wheat cropping system. Soil Tillage Res 166:59–66

Chen Y, Huang B, Hu W, Weindorf DC, Liu X, Yang L (2014) Accumulation and ecological effects of soil heavy metals in conventional and organic greenhouse vegetable production systems in Nanjing, China. Environ Earth Sci 71:3605–3616

Cui H, Ou Y, Wang L, Wu H, Yan B, Li Y (2019) Distribution and release of phosphorus fractions associated with soil aggregate structure in restored wetlands. Chemosphere 223:319–329

Dorji T, Field DJ, Odeh IOA (2019): Soil Aggregate Stability and Aggregate-Associated Organic Carbon under different Land Use/ Land Cover Types. Soil Use Manage 0

E SZ, Li XG, Chen ZM, Li XH, Song JR, Guggenberger G (2012) Long-term fertilization and manuring effects on physically separated soil organic-matter pools under continuous wheat cropping at a rainfed semiarid site in China. J Plant Nutr Soil Sc 175:689–697

Erhagen B, Öquist M, Sparrman T, Haei M, Ilstedt U, Hedenström M, Schleucher J, Nilsson MB (2013) Temperature response of litter and soil organic matter decomposition is determined by chemical composition of organic material. Glob Chang Biol 19:3858–3871

Garcia-Franco N, Martínez-Mena M, Goberna M, Albaladejo J (2015) Changes in soil aggregation and microbial community structure control carbon sequestration after afforestation of semiarid shrublands. Soil Biol Biochem 87:110–121

Ghosh A, Bhattacharyya R, Agarwal BK, Mahapatra P, Shahi DK, Singh G, Agnihorti R, Sawlani R, Sharma C (2019a) Long-term fertilization effects on C-13 natural abundance, soil aggregation, and deep soil organic carbon sequestration in an Alfisol. Land Degrad Dev 30:391–405

Ghosh B, Meena V, Alam N, Dogra P, Bhattacharyya R, Sharma N, Mishra P (2016) Impact of conservation practices on soil aggregation and the carbon management index after seven years of maize–wheat cropping system in the Indian Himalayas. Agric Ecosyst Environ 216:247–257

Ghosh BN, Meena VS, Singh RJ, Alam N, Patra S, Bhattacharyya R, Sharma N, Dadhwal K, Mishra P (2019b) Effects of fertilization on soil aggregation, carbon distribution and carbon management index of maize-wheat rotation in the north-western Indian Himalayas. Ecol Indic 105:415–424

Githinji L (2014) Effect of biochar application rate on soil physical and hydraulic properties of a sandy loam. Arch Agron Soil Sci 60:457–470

Guo Z, Zhang Z, Zhou H, Rahman M, Wang D, Guo X, Li L, Peng X (2018) Long-term animal manure application promoted biological binding agents but not soil aggregation in a vertisol. Soil Tillage Res 180:232–237

Guo ZC, Zhang JB, Fan J, Yang XY, Yi YL, Han XR, Wang DZ, Zhu P, Peng XH (2019a) Does animal manure application improve soil aggregation? Insights from nine long-term fertilization experiments. Sci Total Environ 660:1029–1037

Guo ZC, Zhang ZB, Zhou H, Wang DZ, Peng XH (2019b) The effect of 34-year continuous fertilization on the SOC physical fractions and its chemical composition in a vertisol. Sci Rep-Uk 9

Haghighi F, Gorji M, Shorafa M (2010) A study of the effects of land use changes on soil physical properties and organic matter. Land Degrad Dev 21:496–502

Hernandez T, Hernandez M, Garcia C (2017) The effects on soil aggregation and carbon fixation of different organic amendments for restoring degraded soil in semiarid areas. Eur J Soil Sci 68:941–950

Hu T, Sørensen P, Olesen JE (2018): Soil organic carbon change in arable farming under organic and conventional management

Huang R, Lan M, Liu J, Gao M (2017) Soil aggregate and organic carbon distribution at dry land soil and paddy soil: the role of different straws returning. Environ Sci Pollut Res Int 24:27942–27952

Huang S, Rui WY, Peng XX, Huang QR, Zhang WJ (2010) Organic carbon fractions affected by long-term fertilization in a subtropical paddy soil. Nutr Cycl Agroecosyst 86:153–160

IUSS-WRB (2014): http://www.iuss.org/

Jensen JL, Schjønning P, Watts CW, Christensen BT, Peltre C, Munkholm LJ (2019) Relating soil C and organic matter fractions to soil structural stability. Geoderma 337:834–843

Jiang H, Han X, Zou W, Hao X, Zhang B (2018) Seasonal and long-term changes in soil physical properties and organic carbon fractions as affected by manure application rates in the mollisol region of Northeast China. Agric Ecosyst Environ 268:133–143

Jiang M, Wang X, Liusui Y, Sun X, Zhao C, Liu H (2015) Diversity and abundance of soil animals as influenced by long-term fertilization in grey desert soil, China. Sustainability-Basel 7:10837–10853

Kemper W, Rosenau R (1986): Aggregate stability and size distribution

Li D, Chen L, Xu J, Ma L, Olk DC, Zhao B, Zhang J, Xin X (2018a) Chemical nature of soil organic carbon under different long-term fertilization regimes is coupled with changes in the bacterial community composition in a Calcaric Fluvisol. Biol Fertil Soils 54:999–1012

Li J, Wen Y, Li X, Li Y, Yang X, Lin Z, Song Z, Cooper JM, Zhao B (2018b) Soil labile organic carbon fractions and soil organic carbon stocks as affected by long-term organic and mineral fertilization regimes in the North China plain. Soil Tillage Res 175:281–290

Lima DL, Santos SM, Scherer HW, Schneider RJ, Duarte AC, Santos EB, Esteves VI (2009) Effects of organic and inorganic amendments on soil organic matter properties. Geoderma 150:38–45

Lu R (2000) Analytical methods of agricultural chemistry in soil. China Agricultural Scientech Press, Beijing

Mahieu N, Randall E, Powlson D (1999) Statistical analysis of published carbon-13 CPMAS NMR spectra of soil organic matter. Soil Sci Soc Am J 63:307–319

Mangalassery S, Kalaivanan D, Philip PS (2019) Effect of inorganic fertilisers and organic amendments on soil aggregation and biochemical characteristics in a weathered tropical soil. Soil Tillage Res 187:144–151

Mao J, Olk DC, Fang X, He Z, Schmidt-Rohr K (2008) Influence of animal manure application on the chemical structures of soil organic matter as investigated by advanced solid-state NMR and FT-IR spectroscopy. Geoderma 146:353–362

Mathers NJ, Jalota RK, Dalal RC, Boyd SE (2007) 13C-NMR analysis of decomposing litter and fine roots in the semi-arid mulga lands of southern Queensland. Soil Biol Biochem 39:993–1006

Mi WH, Wu YF, Zhao HT, Wu LH, Liu YL (2018) Effects of combined organic manure and mineral fertilization on soil aggregation and aggregate-associated organic carbon in two agricultural soils. J Plant Nutr 41:2256–2265

Mikha MM, Hergert GW, Benjamin JG, Jabro JD, Nielsen RA (2015) Long-term manure impacts on soil aggregates and aggregate-associated carbon and nitrogen. Soil Sci Soc Am J 79:626–636

Mizuta K, Taguchi S, Sato S (2015) Soil aggregate formation and stability induced by starch and cellulose. Soil Biol Biochem 87:90–96

Naveed M, Moldrup P, Arthur E, Wildenschild D, Eden M, Lamandé M, Vogel H, Jonge LWD (2013) Revealing soil structure and functional macroporosity along a clay gradient using X-ray computed tomography. Soil Sci Soc Am J 77:403–411

Naveed M, Moldrup P, Vogel H-J, Lamandé M, Wildenschild D, Tuller M, de Jonge LW (2014) Impact of long-term fertilization practice on soil structure evolution. Geoderma 217-218:181–189

Padbhushan R, Das A, Rakshit R, Sharma RP, Kohli A, Kumar R (2016) Long-term organic amendment application improves influence on soil aggregation, aggregate associated carbon and carbon pools under scented rice-potato-onion cropping system after the 9th crop cycle. Commun Soil Sci Plan 47:2445–2457

Papadopoulos A, Bird N, Whitmore A, Mooney S (2009) Investigating the effects of organic and conventional management on soil aggregate stability using X-ray computed tomography. Eur J Soil Sci 60: 360–368

Plaza-Bonilla D, Alvaro-Fuentes J, Cantero-Martinez C (2013) Soil aggregate stability as affected by fertilization type under semiarid no-tillage conditions. Soil Sci Soc Am J 77:284–292

Preston CM, Nault JR, Trofymow J (2009) Chemical changes during 6 years of decomposition of 11 litters in some Canadian forest sites. Part 2. 13 C abundance, solid-state 13 C NMR spectroscopy and the meaning of "lignin". Ecosystems 12:1078–1102

Pritchett K, Kennedy AC, Cogger CG (2011) Management effects on soil quality in organic vegetable systems in western Washington. Soil Sci Soc Am J 75:605–615

Pulido-Moncada M, Lozano Z, Delgado M, Dumon M, Van Ranst E, Lobo D, Gabriels D, Cornelis WM (2018) Using soil organic matter fractions as indicators of soil physical quality. Soil Use Manag 34: 187–196

Regelink IC, Stoof CR, Rousseva S, Weng L, Lair GJ, Kram P, Nikolaidis NP, Kercheva M, Banwart S, Comans RN (2015) Linkages between aggregate formation, porosity and soil chemical properties. Geoderma 247:24–37

Rodrigo-Comino J, Davis J, Keesstra SD, Cerdà A (2018) Updated measurements in vineyards improves accuracy of soil erosion rates. Agron J 110:411–417

Sarker TC, Incerti G, Spaccini R, Piccolo A, Mazzoleni S, Bonanomi G (2018) Linking organic matter chemistry with soil aggregate stability: insight from 13C NMR spectroscopy. Soil Biol Biochem 117: 175–184

Shrestha BM, Singh BR, Forte C, Certini G, de Varennes A (2015) Long-term effects of tillage, nutrient application and crop rotation on soil organic matter quality assessed by NMR spectroscopy. Soil Use Manag 31:358–366

Skjemstad J, Clarke P, Taylor J, Oades J, Newman R (1994) The removal of magnetic materials from surface soils - a solid state 13C CP/MAS NMR study. Soil Res 32:1215–1229

Somasundaram J, Reeves S, Wang W, Heenan M, Dalal R (2017) Impact of 47 years of no tillage and stubble retention on soil aggregation and carbon distribution in a vertisol. Land Degrad Dev 28:1589–1602

Sui YY, Jiao XG, Liu XB, Zhang XY, Ding GW (2012) Water-stable aggregates and their organic carbon distribution after five years of chemical fertilizer and manure treatments on eroded farmland of Chinese mollisols. Can J Soil Sci 92:551–557

Trakooyingcharoen P, Gilkes RJ, Sangkhasila K (2012) Effects of land use on some physical, chemical, and mineralogical characteristics of Thai oxisols. Scienceasia 38:82–89

Udom B, Nuga B, Adesodun J (2016) Water-stable aggregates and aggregate-associated organic carbon and nitrogen after three annual applications of poultry manure and spent mushroom wastes. Appl Soil Ecol 101:5–10

Wang H, Guan D, Zhang R, Chen Y, Hu Y, Xiao L (2014) Soil aggregates and organic carbon affected by the land use change from rice paddy to vegetable field. Ecol Eng 70:206–211

Wang X, Jia Z, Liang L, Yang B, Ding R, Nie J, Wang J (2015) Maize straw effects on soil aggregation and other properties in arid land. Soil Tillage Res 153:131–136

Wang Y, Hu N, Ge T, Kuzyakov Y, Wang Z-L, Li Z, Tang Z, Chen Y, Wu C, Lou Y (2017) Soil aggregation regulates distributions of carbon, microbial community and enzyme activities after 23-year manure amendment. Appl Soil Ecol 111:65–72

Wang Z, Wang Z, Ma LJ, Ali Khattak W, Hu W, Meng YL, Zhou ZG (2018) Combined effects of nitrogen fertilizer and straw application on aggregate distribution and aggregate-associated organic carbon stability in an alkaline sandy loam soil. Eur J Soil Sci 69:1105–1116

Weyers SL, Johnson JM, Archer DW, Gesch RW, Forcella F (2018) Manure and residue inputs maintained soil organic carbon in upper Midwest conservation production systems. Soil Sci Soc Am J 82: 878–888

Williams DM, Blanco-Canqui H, Francis CA, Galusha TD (2017) Organic farming and soil physical properties: an assessment after 40 years. Agron J 109:600–609

Wolf B, Snyder G (2003) Sustainable soils: the place of organic matter in sustaining soils and their productivity. CRC Press

Xie JY, Xu MG, Qiangjiu CR, Yang Y, Zhang SL, Sun BH, Yang XY (2015) Soil aggregation and aggregate associated organic carbon and total nitrogen under long-term contrasting soil management regimes in loess soil. J Integr Agric 14:2405–2416

Xu L, Wang M, Shi X, Yu Q, Shi Y, Xu S, Sun W (2018) Effect of long-term organic fertilization on the soil pore characteristics of greenhouse vegetable fields converted from rice-wheat rotation fields. Sci Total Environ 631:1243–1250

Xu L, Wang M, Tian Y, Shi X, Shi Y, Yu Q, Xu S, Li X, Xie X (2019) Changes in soil macropores: superposition of the roles of organic nutrient amendments and the greenhouse pattern in vegetable plantations. Soil Use Manag

Zhang JC, Zhang L, Wang P, Huang QW, Yu GH, Li DC, Shen QR, Ran W (2013) The role of non-crystalline Fe in the increase of SOC after long-term organic manure application to the red soil of southern China. Eur J Soil Sci 64:797–804

Zhang X, Zhu A, Yang W, Zhang J (2017) Accumulation of organic components and its association with macroaggregation in a sandy loam soil following conservation tillage. Plant Soil 416:1–15

Zhao H, Shar AG, Li S, Chen Y, Shi J, Zhang X, Tian X (2018) Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system. Soil Tillage Res 175:178–186

Zheng W, Morris EK, Lehmann A, Rillig MC (2016) Interplay of soil water repellency, soil aggregation and organic carbon. A Meta-Analys Geoderma 283:39–47

Zhou H, Fang H, Mooney SJ, Peng X (2016) Effects of long-term inorganic and organic fertilizations on the soil micro and macro structures of rice paddies. Geoderma 266:66–74

Zikeli S, Deil L, Möller K (2017) The challenge of imbalanced nutrient flows in organic farming systems: a study of organic greenhouses in southern Germany. Agric Ecosyst Environ 244:1–13

Zou C, Li Y, Huang W, Zhao G, Pu G, Su J, Coyne MS, Chen Y, Wang L, Hu X (2018) Rotation and manure amendment increase soil macroaggregates and associated carbon and nitrogen stocks in flue-cured tobacco production. Geoderma 325:49–58