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Composition of a Soil Organic Carbon Increment under Different Vegetable Cultivation Patterns: A Study Using Three SOC Pools

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Abstract: Previous studies suggest that vegetable cultivation increases soil organic carbon (SOC) storage. However, how stable the SOC increment is, and how greenhouse cultivation contributes to the SOC increment in terms of quantity and stability, remains unclear. Soil samples were taken from three typical vegetable cultivation pattern fields: open field (OF), seasonal greenhouse (SG), and permanent greenhouse (PG), as well as adjacent non-vegetable fields. Three conceptual SOC pools, including active (C_a), slow (C_s), and resistant (C_r) pools were fractionated to evaluate SOC sequestration and its stability in vegetable cultivation. The results indicate that vegetable cultivation is associated with greater stored SOC compared with non-vegetable cultivation (SOC increased by 57.9% on average). Using non-vegetable fields as a reference, SOC increments by vegetable cultivation were associated with a higher proportion of C_a (3.7–6.6%) than the reference fields (1.0–2.0%), indicating that the SOC increments might be easily decomposed. Among the three vegetable cultivation patterns, SG, with a higher increase in C_r , is recommended due to its relatively more stable SOC sequestration. Overall, vegetable cultivation could enhance the quantity of SOC, but the stability of the SOC increment is affected by the vegetable cultivation pattern.

Keywords: Open field; Greenhouse cultivation; Soil organic carbon pool; Vegetable cultivation

1. Introduction

The global soil organic carbon (SOC) pool is approximately 1500 Pg (to 1 meter), which makes it the largest carbon pool in the terrestrial ecosystem [1,2]. Any small change in the SOC pool may greatly affect the atmospheric CO₂ concentration. It has been suggested that land use/cover change (LUCC) is the main factor determining SOC storage [3,4]. Vegetable cultivation often requires more intensive management and larger inputs of nutrients and irrigation [5] compared to conventional cereal production. Therefore, conversion from non-vegetable fields (e.g., cereal fields) to vegetable cultivation is considered to be an important land use change that affects the SOC pool [6].

Vegetable cultivation in China has significantly increased in recent years because of high market prices and increasing demand [7]. The vegetable production of China accounted for about 51% of the global vegetable production [8]. In 2016, the area under vegetable production occupied approximately 13.4% of the overall agricultural land in China, which represented a dramatic increase of 2.2% from 1978, representing a total area of 22.3 million ha [9]. Further, besides conventional open field (OF)

cultivation, vegetable cultivation patterns, such as seasonal and permanent greenhouses (SG and PG, respectively), developed rapidly. By 2010, the area of vegetable cultivation in greenhouses had increased to 3.4 million ha in China, accounting for 18% of the total area for vegetable cultivation in this country [10].

Previous research indicates that vegetable cultivation increases SOC. Kong et al. [11] found that the sequestration rates of surface SOC (0–20 cm) were 518 and 469 kg ha^{−1} yr^{−1} after conversion from rain-fed or irrigated land to open vegetable field, respectively. By comparing 20 sets of paired samples, Lei et al. [12] also found that conversion from cereal to greenhouse vegetable fields significantly increased the SOC content (8.9 g kg^{−1} in cereal grain fields versus 11.4 g kg^{−1} in greenhouse vegetable fields). Yan et al. [13] estimated that the accumulation rates of carbon in the surface soil (0–30 cm) of greenhouses' vegetable fields were, on average, 1.37 Mg C ha^{−1} yr^{−1} for a period of 8 years in North China by comparing paired soil samples from adjacent wheat–maize fields. Furthermore, based on the combination of data from both field observations and the literature, Wang et al. [14] concluded that the conversion from conventional vegetable cultivation (OF) to greenhouse vegetable cultivation could substantially enhance the carbon sink potential by 8.6 and 1.3 times for temperate and subtropical areas, respectively. However, total SOC content was not the only indicator for evaluating carbon sequestration in vegetable cultivation. If the increased SOC was easily decomposed to CO₂, carbon sequestration in vegetable cultivation should be re-evaluated. Thus, stability of SOC should also be considered for a more comprehensive evaluation of SOC sequestered in vegetable cultivation, which was ignored by most previous studies.

Carbon in soil is composed of a continuum of materials ranging in age from days for plant residues and root exudates to greater than 1000 years for resistant, humic substances [15]. To investigate the turnover of SOC, a number of models have been developed to fractionate SOC into different pools. For example, SOC was divided into active, slow, and resistant pools according to the mean residence time (MRT) in the Century Model [16,17]. Most researchers suggest that vegetable cultivation, especially greenhouse vegetable cultivation, increases the SOC content and benefits soil carbon sequestration. However, to be sequestered, carbon should be converted from active pools to less reactive intermediate or resistant pools [18] because resistant SOC generally has longer turnover times and the conversion provides information about the long-term potential for SOC sequestration [19].

Although vegetable cultivation probably increases the SOC content, it is still unclear how stable the resulting SOC increment is in terms of MRT of SOC fractions and how greenhouse cultivation contributes to SOC storage in quantity and stability compared with conventional open-field cultivation. Thus, for this study, a combination of acid hydrolysis and long-term laboratory incubation was introduced to fractionate SOC into three pools (active, slow, and resistant carbon) that have different MRTs. Vegetable fields under three main cultivation patterns, including open-field cultivation (OF), seasonal greenhouse (SG), and permanent greenhouse (PG) were selected. By comparing the SOC storage of vegetable fields (VFs) under different vegetable production patterns with that of adjacent non-vegetable reference fields (RFs), the effects of the cultivation patterns on SOC were evaluated.

The objectives of the present study were to (1) investigate the effects of different vegetable cultivation patterns on the quantity of the SOC pool; (2) investigate the effects of different vegetable cultivation patterns on the proportion of the three SOC pools; and (3) identify differences among the three vegetable cultivation patterns in the function of SOC sequestration as measured by both the quantity and stability of the SOC pool.

2. Materials and Methods

2.1. Study Area

Cangshan County, where vegetable cultivation is the most popular form of agricultural production, is located in the south of Shandong Province ($34^{\circ}37'–35^{\circ}06'N$ and $117^{\circ}41'–118^{\circ}18'E$, North China) and has a total area of 1800 km². The climate is warm-temperate with periodic monsoon rain. The mean annual temperature is 13.2 °C, with the lowest of $-1.8^{\circ}C$ in January. The mean annual precipitation is 860 mm. The main soil types are fluvo-aquatic soil, cinnamon soil, and lime concretion black soil according to the Genetic Soil Classification of China (Ustochrepts, Hapludalfs, and Endoaquepts in the U.S. Soil Taxonomy, respectively, according to Shi et al. [20] and Yu et al. [20,21]), which support 34.4, 30.1, and 24.7% of the total agricultural land, respectively [6]. Most agricultural area of Cangshan County was following a rotation of winter wheat and summer maize with limited irrigation and fertilizer input. However, currently, Cangshan County is famous as the southern vegetable garden of Shandong Province and uses diverse vegetable cultivation patterns. The three major vegetable cultivation patterns are open-field cultivation (OF), seasonal greenhouse (SG), and permanent greenhouse (PG). Open-field garlic cultivation has a history of up to 1000 years, and greenhouse vegetable cultivation was introduced to Cangshan County in the early 1980s. In 2010, vegetable land covered an area of 46,000 ha, with an annual yield of 2.25 million tons. OF, SG, and PG covered an approximate area of 290, 90, and 80 km², respectively [22].

OF cultivation in Cangshan County mainly follows a rotation of garlic–maize. Only one vegetable season can be supported because of low fertilizer input and the sensitivity of crops to low temperatures in the open field compared with greenhouses. The SG pattern is almost the same as that of OF during summer, whereas agricultural plastic films are used to cover the cropped area in winter to minimize exposure to low temperatures. With seasonal greenhouses, an annual rotation may culminate in two or three harvests. PG is the most intensive vegetable cultivation pattern, with perennial coverage of plastic films. Vegetables can be continuously cultivated due to high fertilizer and irrigation inputs.

2.2. Soil Sampling and Analysis

Vegetable fields (VFs) under the three cultivation patterns and related reference fields (RFs) were sampled. The sampling sites of OF cultivation were located in Xihe village (lime concretion black soil), SG cultivation sites were located in Bulou village (lime concretion black soil), and PG cultivation sites were located in Xiecun village (fluvo-aquatic soil) (Figure 1). Xihe has a long history of garlic cultivation and is the main region for garlic production in China. The Bulou and Xiecun regions contain the largest concentration of land area under seasonal and permanent greenhouse vegetable production systems, respectively. The RF sampling plot in each site was selected based on an investigation from local farmers, where vegetable was never cultivated before. The VF sampling plots were selected based on a local soil map to ensure that sampling plots in each site shared the same soil type.

Figure 1. The location of the sampling sites of the vegetable fields (VFs) and their reference non-vegetable fields (RFs) in Cangshan County, China.

VFs conversion from RFs were selected for each cultivation pattern. A representative non-vegetable field adjacent to a corresponding vegetable field (ensuring that the sampling plots in each site shared the same soil type) was sampled as a reference for each vegetable cultivation pattern. In total, 14 plots were sampled in August of 2010. The details of the sampled sites are listed in Table 1.

Table 1. A description of the sampling sites in Cangshan County, China.

Sampling Site	Cultivation Pattern	n plots	Vegetable Rotation Type	Tillage Times per Year	Chemical Fertilizer	Organic Fertilizer
					t ha ⁻¹ yr ⁻¹	
Xihe	Open field (OF)	4	garlic–maize	1	0.7–1.5	0.8–1 (Bean cake)
	Reference field (RF _{OF})	1	wheat–maize	1	<0.5	-
Bulou	Seasonal greenhouse (SG)	4	pepper–watermelon	2–4	1.1–1.5	10–12 (Chicken manure)
	Reference field (RF _{SG})	1	wheat–maize	1	<0.5	-
Xiecun	Permanent greenhouse (PG)	3	cucumber–pepper	2–4	3–3.5	20–40 (Chicken manure)
	Reference field (RF _{PG})	1	wheat–maize	1	<1.0	-

In each plot with 4 m × 5 m size, five surface soil (0–20 cm) samples were collected in an “S” pattern by a spade and mixed to form a composite sample, and 1 kg of fresh soil sample was taken to

the laboratory. All samples were air-dried, and any visible living plant material or rocks were manually removed. Samples were broken down by a rubber pestle first and passed through a 2-mm sieve, then part of the samples were grinded by an agate mortar through a 0.149-mm sieve for laboratory analysis. Particle-size distribution was determined by using the pipette method. Soil pH was determined by testing soil extract (1:2.5 soil/water ratio) with a pH meter. The Total SOC (T_{SOC}) was determined by the $K_2Cr_2O_7$ oxidation-titration method, available phosphorus (P) by the Olsen method, and available potassium (K) by a flame spectrometer [23]. Details on the laboratory analysis for the three SOC pools can be found in the Appendix A.

2.3. Statistical Analysis

Using the evolved CO_2 as the input data, Equation (1) was fit with a non-linear regression that used the Marquardt algorithm and an iterative process to find the parameter values (C_a , K_a , and K_s) with the minimum residual sum of squares [24]. Proportions of C_a in the SOC increment ($\%C_a$) after conversion from RF to VFs under different vegetable cultivation were calculated using Equation (1).

$$\%C_a = \frac{C_{a\text{average}} - C_{aRF}}{SOC_{\text{average}} - SOC_{RF}} \quad (1)$$

where $\%C_a$ represents proportions of C_a in the SOC increment; SOC_{average} and $C_{a\text{average}}$ represent the average SOC and C_a in VFs under OF, SG, or PG cultivation; and SOC_{RF} and C_{aRF} represent the SOC and C_a in the relative RFs. $\%C_s$ and $\%C_r$ were calculated using the same method. A t-test was performed to assess the differences of the soil properties between VFs and RFs. Variations of the soil properties between VFs and RFs were calculated first, and one-way ANOVA was used to compare the variations among different vegetable cultivation patterns. Multiple comparisons were performed by the least-significant difference method (LSD). In all analyses, a probability of error smaller than 5% ($p < 0.05$) was considered significant. The SPSS analytical software package (Version 19.0, SPSS Inc., Chicago) was used for all of the statistical analyses.

3. Results

3.1. Soil Properties

The soil basic properties are described in Table 2. Soil texture varied for VFs and RFs under different cultivation patterns. The clay contents of OF and SG soils for VFs were 13.6 and 10.1% higher than those of RFs, respectively, whereas the sand contents were 9.2 and 10.6% lower than those of RFs, respectively. However, the clay and sand contents were not significantly different for PG.

Table 2. The surface soil properties of VFs (vegetable fields) and RFs (reference fields) in Cangshan County, China.

Cultivation Method	sand	silt %	clay	pH	Available P	Available K
					mg kg ⁻¹	
RF _{OF} ^{a)}	22.1	47.9	30.0	6.4	24	104
OF	12.9	43.5	43.6	7.6	13	176
One-sample t test	ns	*	ns	*	ns	*
RF _{SG}	18.6	51.4	30.1	6.5	28	107
SG	8.0	51.9	40.2	6.5	130	283
One-sample t test	*	ns	ns	ns	*	**
RF _{PG}	17.6	64.4	18	6.8	113	156
PG	14.0	65.0	21.0	5.90	257	363
One-sample t test	ns	ns	ns	ns	ns	ns

OF, SG, and PG represent open field, seasonal greenhouse, and permanent greenhouse, respectively. * significant at $p < 0.05$; ** significant at $p < 0.01$; ns, not significant for the t-test (the same below). a) Reference field.

Soil nutrients of RFs varied among the three sampling sites. The available P and K of RF in Xiecun were 113 and 156 mg kg⁻¹, respectively, which were much higher than those of Xihe and Bulou because of higher fertilizer use, as is local custom. The soil nutrients of VFs were higher than RFs for all three vegetable cultivation patterns mainly because of the excessive fertilizer and manure application. The increase of available P was −11, 102, and 144 mg kg⁻¹, while available K was 72, 176, and 207 mg kg⁻¹ for OF, SG, and PG, respectively. The soil nutrients increment in VFs generally followed the pattern OF < SG < PG (Table 2) in accordance with nutrient inputs for the different vegetable cultivation patterns (Table 1). Vegetable cultivation patterns have different effects on the soil properties and nutrients and further impact the SOC.

3.2. SOC and SOC Pool Variations

The SOC of RFs in the present study was only 6.4–7.7 g kg⁻¹ (Figure 2a). However, after conversion to vegetable cultivation, the SOC notably increased by 57.9% on average (4.3, 5.2, and 2.7 g kg⁻¹ for OF, SG, and PG cultivation, respectively). Significant differences between VFs and RFs were observed for the OF and SG cultivation ($p < 0.05$) (Figure 2a). Furthermore, the increment of SOC under SG was higher than that under OF and PG (Table 3), indicating that conversion from RF to SG cultivation could sequester more SOC.

Figure 2. Surface soil organic carbon (SOC) content and fractionating SOC pools of the vegetable fields (VFs) and their reference non-vegetable fields (RFs) in Cangshan County, China. (a) SOC content; (b) Active SOC content; (c) Slow SOC content; (d) Resistant SOC content. The error bars represent standard deviations (the same below).

Fractionating SOC pools demonstrated that, compared with RFs, all of the SOC pools increased in VFs. However, significant differences were observed only in the C_a and C_s pools of OF, and the C_r pools of SG (Figure 2). The ANOVA results indicated that the increment of C_a and C_r under different vegetable cultivation showed limited or no differences, but C_r under SG cultivation was significantly higher than that of OF and PG ($p < 0.05$) (Table 3). Most MRTs of C_a and C_s were longer in VFs compared with RFs, although the differences were not significant (Figure 3).

Table 3. Variation of surface SOC content and fractionating SOC pools between the vegetable fields (VFs) and their reference non-vegetable fields (RFs) in Cangshan County, China. Different letters represent a significant difference ($p < 0.05$).

Cultivation Pattern	SOC	C _a	C _s	C _r
	g kg ⁻¹			
OF	4.26 ± 1.08 ab	0.28 ± 0.08 a	2.52 ± 1.40 a	1.47 ± 1.51 b
SG	5.15 ± 0.82 a	0.19 ± 0.14 a	0.69 ± 0.82 b	4.27 ± 1.53 a
PG	2.71 ± 1.63 b	0.12 ± 0.06 a	1.42 ± 0.79 ab	1.17 ± 0.81 b
Cultivation pattern (F value)	ns	ns	ns	5.82*

Figure 3. Mean residence times (MRTs) of the soil organic carbon pools of the vegetable fields (VFs) and reference non-vegetable fields (RFs) in Cangshan County, China. (a) MRT of C_a; (b) MRT of C_s.

3.3. Proportions of SOC Increment

After conversion to vegetable cultivation, SOC increased for all soil types (the increment was 4.3, 5.2, and 2.7 g kg⁻¹ for OF, SG, and PG cultivation, respectively). Using the paired non-vegetable plots as a reference, the SOC increment by vegetable cultivation was associated with a higher proportion of C_a (6.6, 3.7, and 4.3% for OF, SG, and PG cultivation, respectively), compared with RFs (1.0–2.0%). The proportion of C_s and C_r in the SOC increment was 59.0 and 34.4% and 52.4 and 43.3% for OF and PG cultivation, respectively, which were similar to or lower than the RFs (61.4 and 37.4% and 52.3 and 45.7%, respectively). However, SOC sequestered by SG cultivation was primarily associated with C_r (an average increase of 4.3 g kg⁻¹), while C_s only increased by 0.7 g kg⁻¹ (Figure 2). Therefore, among the three vegetable cultivation patterns, SG increased more SOC compared with PG cultivation. Further, the newly sequestered SOC was more stable compared with that from the OF (Figure 4).

Figure 4. The SOC increment and its proportions of the active, slow, and resistant carbon pools from three vegetable cultivation patterns in Cangshan County, China. %C_a, %C_s, and %C_r represent the increment proportions of the active, slow, and resistant carbon pools, respectively.

4. Discussion

4.1. SOC Increment Under Vegetable Cultivation

Huang-Huai-Hai plain, where Cangshan County is located, is one of the most important crop production areas of China [25,26]. However, due to continuous production and tillage without enough nutrient input, the SOC of the cropland is usually at a low level. After conversion from crop to vegetable cultivation, SOC increased by 57.9% on average, which was greater than that after conversion from crop to greenhouse vegetable cultivation in a similar region (42.3%) [13].

Soil organic carbon commonly declines in intensive cropping systems [27]. However, SOC increased with the agricultural land-use intensity (conversion from non-vegetable to vegetable field) in the present study. This increase of SOC mainly results from the increase of net primary productivity (an increasing amount of residues returned to the soil) and intensification of agricultural inputs: fertilizer, irrigation, and manure [28,29]. Large amounts of manure were utilized by vegetable cultivation in Cangshan County and offset greenhouse gases released from tillage or microbial decomposition [30,31]. Furthermore, studies have found a significant relationship between SOC and the clay content, because clay content could offer a chemical protection of SOC from microbial decay [32]. In the present study, OF and SG cultivation might increase the clay content, leading to an extra increase of SOC compared with PG. The clay content increased for two main reasons. First, the soil under OF and SG cultivation is lime concretion black soil, while the soil under PG cultivation is fluvo-aquatic soil. Based on a previous soil survey, lime concretion black soil has an excessive clay content. In contrast, fluvo-aquatic soil has a smaller clay content and is always used for intensive PG cultivation [33]. In addition to the soil type, the cultivation patterns may have an impact on the soil texture through an external input, e.g., irrigation from the sediment-laden water of the Yellow River could increase the clay content [34]. A local investigation revealed that a water-logged organic compost was applied to VFs to improve vegetable quality. The compost is a mixture of green manure with pond and river sediment that is rich in clay content. Thus, vegetable cultivation might increase the clay content. However, the clay content seems to accumulate more easily in the surface soil of lime concretion black soil than fluvo-aquatic soil because of the different soil texture [35]. Vegetable cultivation increased the SOC content; however, the characteristics of the SOC pools should be determined to evaluate their effects on SOC stability.

4.2. SOC Pool Variations of the Increment

The distributions of the three fractionating pools of SOC are distinctly different according to land use, primarily because the chemical components of vegetation vary greatly, resulting in unique effects on the SOC decomposition rate [36]. The active carbon pool accounted for 3.4, 2.2, and 2.7% of the total SOC for VFs under OF, SG, and PG cultivation, respectively. The proportion was higher than that of forest soil, e.g., 0.4–1% associated with a tree farm in Southern Appalachia [37] and 0.9–2.4% for four types of forests in China [24], and was similar to that of agricultural land (1.2% for paddy and 3.5% for upland) in mid-subtropical China [36]. Vegetable land is a specific agricultural land-use type consuming large amounts of fertilizer and manure. Chicken manure is the most popular manure type for vegetable cultivation in Cangshan County. As chicken manure has a fairly high decomposition rate [38], it might contribute to the high active carbon pool in SOC of vegetable land soils. The organic materials in forests decompose much more slowly than in agricultural land [36]. This can explain why the vegetable land acquires a higher proportion of C_a than the forest soil.

4.3. Effect of Vegetable Cultivation Pattern on the Stability of SOC

Vegetable cultivation consumed large amounts of nutrients (Table 1) and resulted in the increase of both the yield and biomass. However, for vegetable production, SOC derived from crop residue is typically lower [39]. The SOC increment from vegetable cultivation was mainly from root residues (including exudates) and manure input [13,40]. These two sources of SOC are considered to decompose easily [15,38] and have a high proportion of C_a . However, the quantitative contributions of

biomass, root residues, and manure to the different SOC pools have not been discovered, and require further investigation.

In addition to the sources of the SOC increment, the environment of vegetable cultivation also had an impact on SOC stability. Greenhouse vegetable cultivation (especially PG) always maintains a high temperature and soil water content, accelerating the decomposition of SOC and release of CO₂ to the atmosphere [41,42]. Therefore, PG demonstrates the shortest MRT of C_a and the lowest SOC increment (Figures 3 and 4).

SG out-performed both OF and PG. The root residues and manure inputs of SG were higher than those of OF, whereas the MRT of both C_a and C_s were longer than those of PG (Figure 3). Thus, SG is considered to be the most beneficial cultivation pattern for increasing SOC sequestration in North China compared to the other patterns.

The present study was based on a spatial soil survey sampling. However, spatial distribution of sampling plots would introduce variance and uncertainty [43]. Therefore, more experimental plots should be conducted for more reliable results to investigate the effects of different vegetable cultivation patterns on SOC.

5. Conclusions

Vegetable cultivation significantly increased SOC compared with the reference non-vegetable fields, with vegetable fields under OF, SG, and PG cultivation increasing SOC by 4.3, 5.2, and 2.7 g kg⁻¹, respectively (by 57.9% on average). Given the conversion from non-vegetable cultivation, vegetable fields could be a carbon sink and enhance the agricultural SOC storage. However, SOC stability was affected by the vegetable cultivation patterns. Using the paired non-vegetable fields as a reference, the SOC increment by vegetable cultivation was associated with a higher proportion of C_a, but a lower proportion of C_s and C_r compared with RFs. This result indicated that the SOC increment from vegetable cultivation might be not stable. Vegetable fields under SG cultivation are associated with a high vegetable output and stable SOC sequestration. SG cultivation is, therefore, preferred to balance the demands for both the environment and agriculture in the region. Our research results could provide a reference for studies in vegetable cultivation regions of North China.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A Appendix

Based on the first order kinetics equation (Equation (2)), SOC was fractionated into active, slow, and resistant pools [19].

$$C_{sot} = C_a \times \exp(-K_a \times t) + C_s \times \exp(-K_s \times t) + C_r \times \exp(-K_r \times t) \quad (2)$$

where C_{sot} is the total organic carbon at time *t*; C_a and C_s are the values of the active and slow pools; K_a, K_s, and K_r are the decomposition rate constants for the active, slow, and resistant pools, respectively; and C_r is the value of the resistant carbon pool as determined from the residue remnants of acid hydrolysis [19,24]. The value of C_s is defined using Equation (3), with T_{SOC} representing the total SOC. Therefore, the model estimates only three variables: C_a, K_a, and K_s.

$$C_s = T_{soc} - C_a - C_r \quad (3)$$

The MRT for each pool was calculated as the reciprocal of the decomposition rate constant (K^{-1}) in the three-pool first-order model. The MRT of C_r is commonly assumed to be 1000 years [19]. By converting Equations (4) and (5) to the passive pool MRT in the laboratory [44], we obtained $K_r = 1/MRT_{lab}$,

$$MRT_{lab} = MRT_{field} / Q_{10} \quad (4)$$

$$Q_{10} = 2^{[(25-MAT)/10]} \quad (5)$$

where MRT_{lab} represents the passive pool MRT in the laboratory; MRT_{field} represents the passive pool MRT in the farmland; MAT is the mean annual temperature in the research area; and Q_{10} is the temperature sensitivity coefficient, which is the increase in SOC decomposition that corresponds to each 10 °C increase in the soil temperature [15].

To estimate the three variables and fractionate SOC among the active, slow, and resistant pools, patterns of carbon release from soil incubations were used [37]. For laboratory incubation, 100 g of each sample (passed through a 2-mm sieve) was incubated in 250-ml glass jars in the dark at 25 °C with a 60% water holding capacity for 94 days. However, a large flush of CO_2 evolved after rewetting the air-dried soils. The flush is the result of the decomposition of the microbial necromass present in dried soil and lysed by the rewetting process as well as the rapid growth of the microbial biomass in the new ideal environment [45]. Thus, samples were incubated for 7 days prior to analysis to remove the effect of the large flush of CO_2 [46].

The water holding capacity was estimated by a volumetric soil water method. The jars were normally closed, but were opened periodically to maintain aerobic conditions. Water loss in the jars was monitored by weight and replenished after opening. No leaching occurred during the course of incubation. The evolved CO_2 was trapped in 25 ml of 0.4 N NaOH. A jar without soil was run simultaneously as a control. Evolved CO_2 was precipitated by the addition of $BaCl_2$ and measured by titration of residual NaOH to pH 7.0 with 0.4 N HCl [24]. The evolved CO_2 was measured 12 times at 2, 5, 10, 17, 24, 31, 38, 45, 55, 65, 79, and 94 days from the start of the incubation.

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