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Soil organic carbon in small watershed terraces and association with physical properties

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Abstract

The organic carbon, physical properties, and their relationship in terrace soil from Huanghuadian watershed in Inner Mongolia, China, were determined in this study. The soil organic carbon concentrated at the surface. The physical properties showed variations with the soil depth. The soil organic carbon contents were significantly correlated with contents of water, clay, bulk density, and sand, while non-significant correlation with silt and nutrient. Path analysis showed that the clay content was the major influence factor on the variation of soil organic carbon. The clay can hold water, then promotes plant growth and thus increase soil organic carbon.

Keywords: Huanghuadian watershed, Organic carbon, Path analysis, Soil physical properties, Terrace

Introduction

Soil is the carrier of nutrient conversion and the largest carbon storage in the earth system (Schimel, 2013; Averill *et al*., 2014). Soil organic carbon is closely related to soil structure and fertility and is commonly used as a key indicator for assessing soil quality (Arthur *et al*., 2014). Among the different source of soil organic carbons, the farmland soil organic carbon is the most active part of the soil carbon pool and changes within short time, which affects the global carbon cycles (Oost *et al*., 2007; Jha *et al*., 2012). Terrace is one of major farmlands resource in China and plays an important role in maintaining the grain safety, ecological safety and social stability in ecological weak zones.

In ecological weak zones, watersheds play important role in soil-water loss and exploitation/ administration and have potential economic and social benefits (Raghuwanshi *et al*., 2003). For example, watersheds have certain water supply conditions and provide irrigation for the farmlands in the semiarid areas. There are large numbers of terraces in the watersheds in semiarid areas of China. The soil fertility of terraces is very important to the local for sustainable agricultural development in the semiarid areas. Thus, it is urgent to study the methods that could improve the soil fertility of terraces. The previous study showed that improvement of soil organic carbon was a manifestation of improved soil fertility (Tiessen *et al*., 1994). In general, soil organic carbon is affected by soil physical properties (e.g. bulk density and moisture), and thereby impact the growth and yields of crops and the sustainable development of agriculture (Seulbi *et al*., 2009; Xue *et al*., 2018). Earlier few studies have reported the relationship between soil organic carbon and physical properties (Seulbi *et al*., 2009; Boivin *et al*., 2010; Xu *et al*., 2016). However, little information is available on the watershed terraces in semiarid areas of China.

In this study, we collected terraces soil from the Huanghuadian small watershed. Terraces are a typical type of farmlands in the study area. This watershed is located in a semi-arid area and has a long history of fertile lands and planting. The purpose of this study was to measure soil organic carbon and physical properties of terrace from the Huanghuadian small watershed. The path analysis was used to explore the variation of soil organic carbon and its relationship with soil physical properties. This study was also expected to provide basic data and theories on improvement soil fertility and agricultural yield in watershed terraces in semiarid areas.

Materials and Methods

Study area: Huanghuadian small watershed (42°17’-42°33’ N, 119°36’ -119°53’ E) is located in west of Aohan Banner, Inner Mongolia, China. This small watershed covers 32 km^2, with about 38.41% of cultivated lands (12.29 km^2). The cultivated lands include 11 km^2 of dry lands and 1 km^2 of irrigated lands. The study area belongs to the medium-temperature semiarid continental monsoon climate. The annual rainfall and evaporation are 400-470 mm and 2290-2400 mm, respectively. The annual sunshine duration is 2940-3060 h. The soil type is chestnut soil. The crops in the study area were single cropping and mainly included maize and millet.

***Soil sampling and analyses*:** The maize is the dominant crop in the study area, accounting for 73% of total planting area. Thus, the sample sites were mainly selected from maize dry-land terraces. According to the land use map of Aohan Banner and the terrace distribution of Huanghuadian watershed, we selected 12 sample plots in the terraces in this watershed. In each plot, four sampling sites were selected. In each site, soil samples were collected in surface layer (0-20 cm), middle layer (20-40 cm), and bottom layer (40-60 cm) with a ring sampler. The soil samples were collected in triplicate in each layer. A total of 144 soil samples were collected from different layers.

Soil water content was tested by an aluminum box drying method (in an oven at 105 °C) and computed as soil water content = (wet weight - dry weight)/dry weight ×100%. Soil bulk density was detected by a ring knife method according to soil analytical methods of China. Soil grain composition was measured by a Master sizer 3000 laser grain-size analyzer. Soil organic carbon contents were measured by a potassium dichromate-sulfuric acid method according to the standards methods of Soil Science Society of China. According to the Second Soil Census of China, organic matter was classified into six grades: I (>40 g/kg), II (30-40 g/kg), III (20-30 g/kg), IV (10-20 g/kg), V (6-10 g/kg), and VI (<6 g/kg). In this study, the grade I and II, grade III and IV, grade V and VI, were considered as high, medium and low levels, respectively.

***Statistical analysis*:** Data computation and plotting were conducted on Excel 2007. Analysis of variance (ANOVA), correlation analysis and path analysis were used in this study by SAS 9.0.

Results and Discussion

Terrace soil organic carbon: The organic carbon contents range from 0.76 to 11.19 g/kg in terraces soil (Table 1). The average organic carbon content in different layers ranged from 5.49 to 7.58 g/kg. In the present study, the organic carbon content gradually decreased with the depth (Table 1). For example, the highest organic carbon content was found at the surface layer, accounting up to 37.92% of the total organic carbon. This indicates that there was an evident aggregation of organic carbon at the surface layer. Our findings were in agreement with other studies on farmlands (Chen *et al*., 2015), forest (Goberna *et al*., 2006) and woodlands (Guo *et al*., 2014).

In this study, the soil organic carbon contents were not significantly different between the surface and middle layers ($P>0.05$). However, the organic carbon contents at both the surface and middle layers were significantly higher than those in the bottom layer ($P<0.05$). This indicated that the soil organic carbon in terraces mainly distributed at the surface and middle layers. It was because the surface and middle layers were supplied by external organic manure and enriched with roots. Also the favorable conditions of ventilation and heat contributed to the micro-organic decomposition of soil organic matter into organic carbon (Frouz *et al*., 2009). On the contrary, the bottom layer soils are not ploughed for long time and restricted from matter exchange with the external world, which are unfavorable for organic carbon accumulation.

In general, coefficient of variation (CV) reflects the variation degree of soil organic carbon at different soil depths. The CV was classified into three grades following the method of Zhang *et al*. (2011): CV<10% corresponds to weak variation, 10%$\leq$ CV<100% indicates a medium variation, and CV$\geq$100% signals a strong variation. In this study, the organic carbon contents at different soil layers of terraces in Huanghuadian watershed belong to medium variation. The largest and smallest CVs were found in the surface and bottom layer, respectively. This was because the surface layer undergoes the severe influence by human activities. Thus, the organic carbon contents there fluctuated largely. Moreover, the average soil layer depth with efficient ploughing in this watershed was 0-20 cm, indicating that the surface layer was disturbed by the ploughing and management. Contrary, the bottom layer is basically isolated from the external

Table 1. The soil organic carbon contents in terraces soil

Layer (cm)	Maximum (g/kg)	Minimum (g/kg)	Mean (g/kg)	Standard deviation (g/kg)	CV (%)	Skewness value	Kurtosis value
0-20	11.19	2.57	7.58a	2.86	46.81	-0.112	0.846
20-40	10.84	0.76	6.92a	2.43	37.56	-0.256	0.002
40-60	8.27	1.36	5.49b	1.82	33.29	0.333	0.485

The letters in the same column represent significant difference at P<0.05, and the same letters indicate insignificant difference world and thus is rarely influenced by environmental and artificial factors. Thus, the soil organic carbon contents in this layer are very stable.

As shown in Table 1, the skewness coefficients in the surface and middle layers were both negative, indicating organic carbon distributions showed a left-side long-tail and contain large proportions of large data. On the contrary, the skewness coefficient in the bottom layer was positive, indicating organic carbon distribution showed a right-side long-tail and contains large proportions of small data. These results were consistent with the mean soil organic carbon distributions at different soil layers, which further proved the soil organic carbon content at the bottom layer was low, and the organic carbon contents in the terraces tended to aggregate at the surface layer.

In the present study, K-S statistical test was used to test the data. The result showed that the soil organic carbon contents generally obeyed a normal distribution, indicating the measured data were representative. In the study area, the organic carbon contents were concentrated between 4 and 6 g/kg (Fig 1). The mean organic carbon content in this small watershed was 6.66 g/kg. According to the van Bemmelen factor of 1.724 used in China as the coefficient to convert organic carbon, the mean soil organic matter in the farmlands there was 11.48 g/kg. Compared with the standard of the Second Soil Census in China: the six grades of organic matter from poor level (<6 g/kg) to rich level (>40 g/kg), the organic matter in this study area was categorized as a medium level.

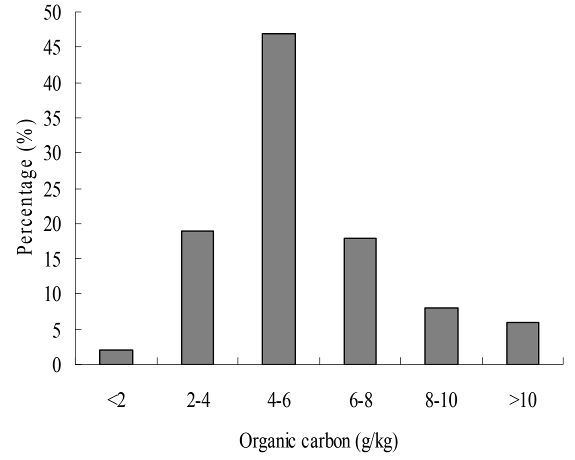

Fig 1. Frequency distribution of soil organic carbon

Soil physical properties: The soil physical properties of the terraces in Huanghuadian small watershed were recorded (Table 2). It was seen that the soil bulk density increased with the depth, indicating the top-layer soils were loose. It was due to the accumulation and decomposition of crop/weed litters after the harvest. As reported earlier, the plant roots disturbance can change the soil structures and thereby increase soil porosity and reduce soil bulk density (Stumpf *et al.*, 2016). This indicated that the reduction of surface-layer bulk density was related to the frequent artificial ploughing and management. The loosening effects on soils by artificial management and crop growth could improve soil structures and contribute to plant growth. Moreover, the reduction of bulk density promoted the downward extension of roots, and improved the soil productivity and the carbon sequestration effect with roots as the source. Since the roots of maize were mostly distributed at the surface layer, the presence of extensive roots loosened the soils, while the bottom-layer soils became tighter after years of compaction. Therefore, there was low soil bulk density at the surface layer.

Similar to the bulk density, the water contents also increased with the depth in the study area. Our results are in agreement with the previous studies (Yashchenko *et al.*, 2016). It could be explained by two processes. One process was the irrigation. In general, the water

Table 2. Soil physical properties at different layers

Soil depth (cm)	**0-20**	**20-40**	**40-60**
Bulk density (g/cm^3)	1.42±0.13^{a}	1.47±0.12^{ab}	1.53±0.11^{b}
Water content (%)	11.38±2.63	11.55±3.51	12.26±2.97
Clay content (%)	1.97±0.64	1.83±0.44	1.72±0.55
Silt content (%)	41.10±8.49^{a}	39.62±10.97^{a}	40.14±8.34^{a}
Sand content (%)	55.95±8.84	57.56±8.86	57.96±11.27
Total nitrogen (mg/kg)	0.68±0.04^{a}	0.64±0.03^{a}	0.41±0.02^{b}
Available P (mg/kg)	5.46±0.44^{a}	4.98±0.35^{a}	3.10±0.24^{b}
Available K (mg/kg)	91.12±6.45^{a}	86.65±4.52^{a}	73.20±3.42^{b}

a and b indicate the differences at different levels between indices would move downwards from the surface layer due to the gravity. Thus, the soil moisture mainly concentrated at the bottom. The other process was evaporation. It is well known that the evaporated amount of soil moisture gradually declines from the top layer to the bottom (Tavili *et al*., 2009). Therefore, the high water contents were found at the soil bottom in this study.

In this study, there were different variations in different soil particle (Table 2). The soil clay contents gradually decline with the depth. However, the sand contents gradually increase, and the silt contents first decline and then increase. However, the study of Agoumé and Birang (2009) showed that the sand and silt decreased with the soil depth whereas clay increased with it. This difference was likely correlated to the topography, soil texture, and land use types (Zinn *et al*., 2005; Agoumé and Birang, 2009).

The contents of the total nitrogen, available P, and available K were all decreased with the depth (Table 2). These findings were consistent with the study of Baljit *et al*. (2016). On one hand, the fertilization management generally occurred in the surface layer. On the other hand, that the plant roots mainly distributed in the surface and middle layers, and thus increased the nutrient content. In the study area, the contents of them in both surface and middle layers were significantly higher than those in bottom layer ($P<0.05$), suggesting that the nutrient were also mainly concentrated at the surface layer.

Relationship between soil physical properties and organic carbon content: The correlation analysis between soil organic carbon and physical properties in the terraces was also performed. Among 8 parameters of the soil physical properties, four parameters were significantly correlated with soil organic carbon content in the terraces of Huanghuadian watershed (Fig 2). Both the water content and clay content were significantly positively correlated with soil organic carbon, whereas bulk density and sand content showed an inverse relationship ($P<0.01$). The other parameters, such as silt and nutrient, were not significantly related to soil organic carbon content ($P>0.05$), indicating that they were not the important influencing factors on soil organic carbon content variation in the terraces of Huanghuadian watershed.

In the study area, the organic carbon content was significantly correlated with both the water content and clay content. This was because both the water and clay can improve the soil fertility, and then increase the organic carbon content. It is well known that water plays a vital role in plant growth. In particular, water is the key constraint for plant growth in the semi-arid area (Zhang *et al*., 2014). Our study area was located in a semi-arid region and the plant growth was suffered from the scarce water resources. The plant growth was significantly positively correlated with water supply. Once the soils contain more water, the plant grew better and the roots contained more secretion and organic matter accumulation, which promoted the carbon transport in soils (Mahesh *et al*., 2017). The soil organic carbon thus improved with increase in water content. The soil clay content could also enhance soil aggregation and thus increased the organic carbon content (Tang *et al*., 2007). Moreover, the clay had high capability in the water-holding and promoted the plant growth. Therefore, both the water content and clay content were significantly positively correlated with soil organic carbon.

The bulk density is a basic physical property of soils and one indicator of the soil porosity and elasticity. It may be affected by the water, fertilizers, gas, and heat in soils. In general, the low bulk density soil had high water and fertility attributes and thus enhanced the plant growth and then increased soil organic carbon (Tracy *et al*., 2013). In the present study, the sand content was also significantly negatively correlated with soil organic carbon (Fig 2). This was because that the sand had high permeability, and thus had low capability in water-holding and fertilizer-holding. The limited water and fertility might have led to plant growth inhibition. Thus, the soil organic carbon was decreased. Additionally, the sands were featured by large porosity and high ventilation, leading to the organic carbon decomposition or mineralization. Thereby both the bulk density and sand content were significantly negatively correlated with soil organic carbon.

To clarify further the direct and indirect effects of soil physical properties on organic carbon contents and to clarify the relationship between them, the path analysis were conducted in this study. The correlation matrix included the soil organic carbon (y) and the significant parameters of the soil physical properties such as bulk density (x_1), water content (x_2), clay content (x_3), and sand content (x_4). According to the formula of residual effect of path coefficients, the residual effect is $P_{uy}=0.131$. This value is close to 0.10 and smaller than 0.20, indicating the selected physical properties can well clarify the variations of organic carbon in this study.

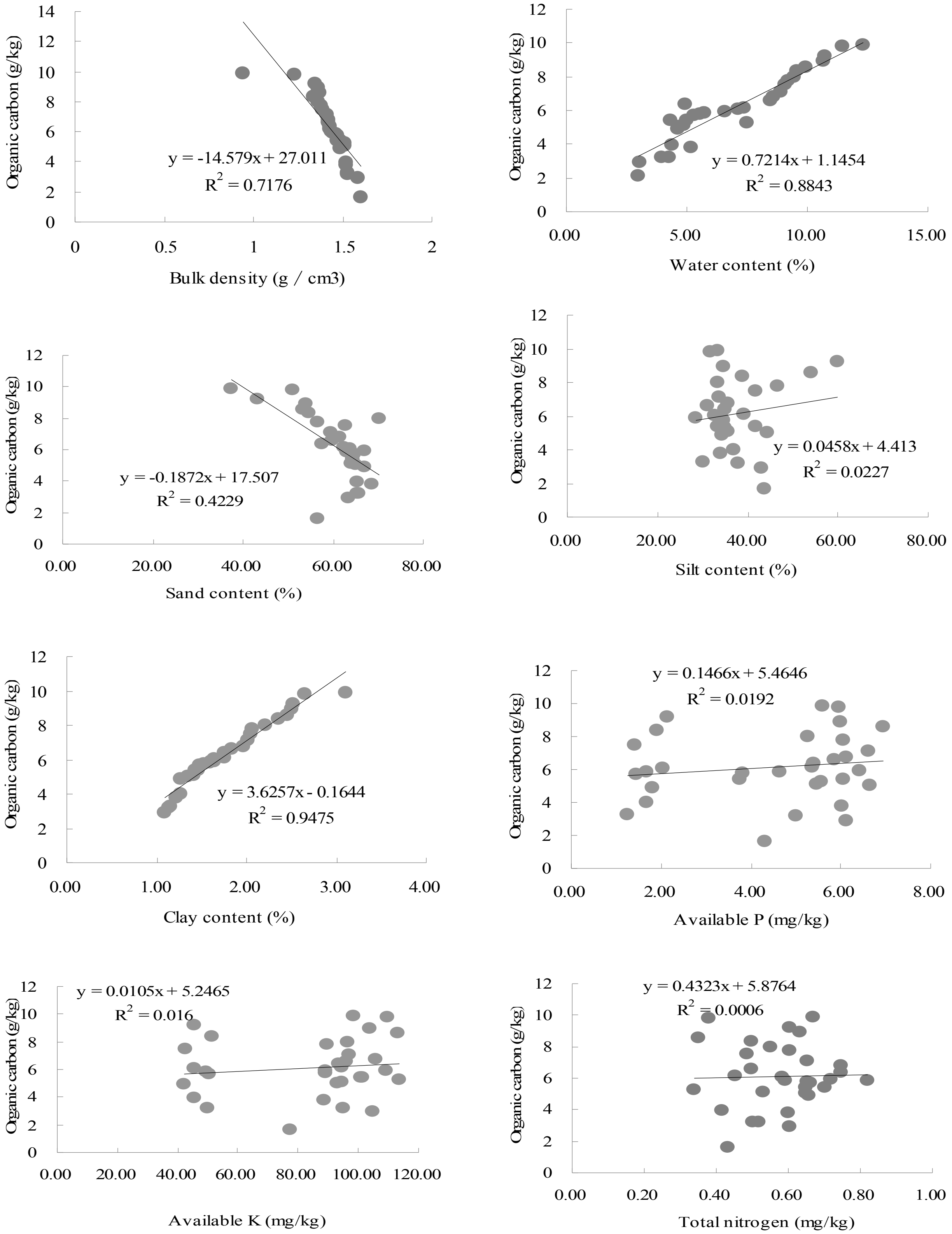

Fig 2. Correlation between soil physical properties and organic carbon content

Table 3. The path coefficients of soil organic carbon and soil physical properties

Variable	x_1	x_2	x_3	x_4	y
x_1	0.211*	-0.406	-0.641	-0.019	-0.855
x_2	-0.167	0.546*	0.621	-0.061	0.939
x_3	-0.196	0.441	0.716*	0.013	0.974
x_4	-0.068	-0.538	-0.167	0.061*	-0.712

The number with star (*) is the direct path coefficient; y is the total path coefficient, and others are indirect path coefficients

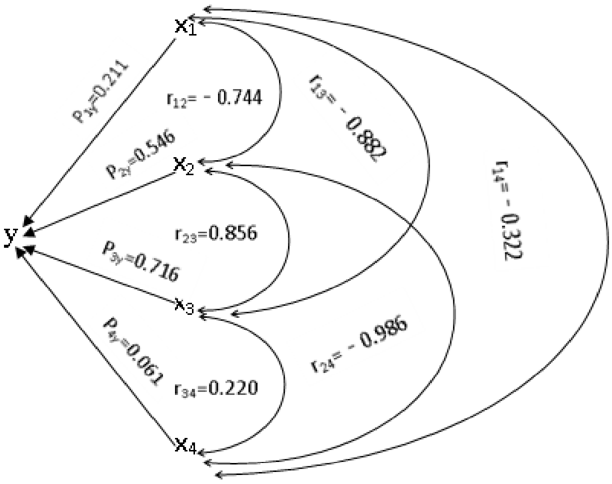

Fig 3. The path coefficient map of soil organic carbon content and soil physical properties in terrace

In this study, the direct effects of the tested physical properties on organic carbon content rank as follows: clay content > water content > bulk density > silt content (Table 3 and Fig 3). The indirect effects of bulk density and water content on organic carbon through the action of clay content were very low. In particular, bulk density did not directly affect the organic carbon contents, while direct effect of clay content on organic carbon contents were larger than the total indirect effect of all other factors. This indicated that the clay content played an important effect on soil ventilation and water conservation. Clay content played a large negative indirect effect on soil organic carbon through the action of water content (Table 3, $P_{2y}*r_{24}$=-0.538), while the direct effect was low. The possible reason was the fact that the Huanghuadian watershed is located in semi-arid area, where water resources are scarce due to high evaporation/ transpiration (Zhang *et al*., 2014). Consequently, the plant growth was largely dependent on the soil capability on water-holding. As discussed above, the clay had high capability on water-holding, it directly promoted the plant growth and thereby improved of soil organic carbon.

Path analysis was successfully applied in examining the direct and indirect effects of soil properties on organic carbon (Ding *et al*., 2013; Sackett *et al*., 2013). In this study, we firstly used this approach to analyze the direct and indirect effects of soil properties on organic carbon in terrace soils in Huanghuadian watershed. These findings are very useful in improvement of soils in watershed terraces.

Conclusion

Soil organic carbon contents of terraces in Huanghuadian watershed decreased with increase in depth. There were variations in the soil physical properties. Soil bulk density, water content, and sand content gradually increased with soil depth, while clay and nutrient (total nitrogen, available P, and available K) gradually decreased. The silt contents first declined and then increased. In this study, the water content and clay content were all significantly positively correlated with soil organic carbon, while the bulk density and sand content showed an inverse relationship. The silt and nutrient were not significantly related to the soil organic carbon. The path analysis showed that the clay content played a key role in influencing the variation of soil organic carbon contents.

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