MINERALIZATION CHARACTERISTICS OF ORGANIC CARBON IN SHORT-TERM RECONSTITUTED SOILS OF SOFT ROCK AND SAND

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Abstract

To study the effects of different proportions of soft rock added to aeolian sandy soil on organic carbon pools, a field plot experiment was carried out. The parameters related to soil organic carbon mineralization were fitted by first-order kinetic equation. The results showed that the organic carbon mineralization rate can be divided into two stages: a rapid decline of 1 - 8 days and a steady decline of 8 - 30 days. The organic carbon mineralization rate and cumulative mineralization showed a trend of C1 > C3 > C2 > CK. The k values of CK and C2 treatments were significantly higher than those of C1 and C3 treatments. The cumulative mineralization rate and C_0/SOC value of C2 treatment were the minimum in complex ratio treatment. The wheat yield treated with C2 treatment was the highest and there was no significant correlation with mineralization parameters. It can be seen that 1 : 2 volume ratio of soft rock to sand can indirectly promote the accumulation of organic carbon and crop yield.

Introduction

The soil organic carbon pool in terrestrial ecosystems is about 3 times more than that of plant carbon pools (Smith *et al.* 2008). The organic carbon, exchanged between soil and atmosphere accounts for about two-third of the total carbon storage of surface ecosystems. A slight change in it will have certain impact on greenhouse gas emissions (Chhabraa *et al.* 2003, Degryze *et al.* 2004). Soil organic carbon mineralization is an important part of the carbon cycle in terrestrial ecosystems. The change of land resources caused by human activities often causes the changes in atmospheric CO_2 concentration through the effects on terrestrial ecosystems. This in turn affects the carbon cycle and the climate change process (Stump *et al.* 2018). Therefore, in recent years, the research on soil carbon cycle by human activities has attracted much attention and has become the core issue of multidisciplinary research.

In the arid and semi-arid areas of Shaanxi Province, Shanxi Province, Inner Mongolia and in other arid areas there are two important soil resources. These are the soft rock (soft rock) and aeolian sandy soil (sand) which undergo routine weathering. As a result, serious soil erosion and loose texture in the soil components do occur causing low nutrient content and poor soil structure. Chinese and foreign experts term this condition as "Earth Environment Cancer". It can be seen that the geographical hazard of the soft rock and sand areas determines the urgency and difficulty of ecological restoration in the region (Wang *et al.* 2007). Han *et al.* (2012) studied the structure and physicochemical properties of sandstone and sand, and analyzed that the two resources can be

mixed into different proportions to form "new soil". They also suggested that the optimum proportion of soft rock: sand suitable for planting crops ranged between 1 : 5 and 1 : 1. At present, the technology of using soft rock to improve aeolian sandy soil has been widely used. Currently 1573.3 hm^2 of newly cultivated land has been added and through this the resource utilization of the soft rock and the improvement of the regional ecological environment have been realised. She *et al.* (2015) studied the nutrient content and hydraulic parameters of the soft rock and sand compound soil. They proposed that the fertilizer retention performance and the available nutrient content of the compound soil can be effectively improved with the increase of the soft rock content and adding sufficient water, respectively. Wang (2016) mixed sand and soft rock according to a certain proportion to form a new type of soil. He mainly analyzed the texture changes and biochemical indexes of crops grown in that new soil. The result showed that the soil texture changed from sand to silt loam as the proportion of soft rock increases. Moreover, the photosynthetic rate of crops and the activity indexes such as antioxidant enzymes showed a trend of increase first and then decrease. It can be seen that for the two low-utilization resources of soft rock and aeolian sandy soil, many researchers have already performed a number of studies on the resource utilization and obtained certain achievements. However, the research reports on the combination effect of the soft rock and the aeolian sandy soil has been getting rated more and more. Nevertheless, under the background of global warming at present, one should not only improve the utilization rate of waste resources but also maintain the sustainable development of ecological environment. The issue of greenhouse gas emissions from the compounded soil is an area which has not yet been addressed by researchers properly. The carbon source or sink of the composite soil also needs to be studied further.

The experimental plot was set up in Fuping County pilot test base of traditional provincial land engineering technology research institute. The pilot test base was a transitional stage from theoretical experiment to production practice. Corn and wheat were used as economic crops in the Mu Us Sandy area. In order to simulate the applicability of reconstituted soil for planting crops with soft rock and sand, two specific varieties of corn (Jincheng 508) and wheat (Xiaoyan 22) were specially planted. The team members of different research groups have done some research on the soft rock and sand compound soil in the early stage (Shen *et al.* 2013, Wang *et al.* 2017, Li *et al.* 2018a, Sun and Han 2018,). The results showed that the increase of the ratio of soft rock to sand can effectively increase the capillary porosity and decrease the water infiltration coefficient of the aeolian sandy soil. The texture was also improved to a certain extent, and the macroscopic mechanics showed strain hardening phenomenon and nonlinear characteristics. After adding soft rock, the final water content of the improved soil was significantly higher than that of the aeolian sandy soil, which was beneficial to the maintenance of water and fertilizer. Research results also showed that the toxic effect of lead in aeolian sandy soil can be effectively reduced with the addition of the proportion of soft rock, and the larger the proportion of soft rock added, the greater the degree of reduction (Li *et al.* 2018a). Researches, addressed so far to the problem in the early stage, mainly inferred the hydraulic properties, fertility and adsorption of the soft rock and aeolian sandy soil. But they lacked the investigation on the carbon source and sink effects of the compound soil. Therefore, the purpose of this study on the one hand, was to clarify the carbon mineralization strength of the compound soil in different proportions of soft rock and sand. On the other hand, to clarify the carbon fixation effects of different proportion of mixed soil and to provide the way and basis for the sustainable development of regional ecology.

Materials and Methods

The experimental plot was set up in Fuping County pilot test base of Shaanxi provincial land engineering technology research institute. Fuping County (108°57′ - 109°26′E，34°42′ - 35°06′N)

is the transition zone between the Guanzhong plain and the northern Shaanxi plateau, and belongs to the gully region of the Weibei Loess Plateau. In terms of elevation, the terrain is high in the north and low in the south. It slopes from the northwest to the southeast. The elevation in the territory is 375.8 - 1420.7 m MSL. The area belongs to the continental monsoon warm zone with semi-arid climate. The annual average sunshine hours, temperature and precipitation is about 2389.6 hrs, 13.1°C and 527.2 mm, respectively.

The field study was carried out in 2016, and four treatments of soft rock and sand in a volume ratio of 0 : 1 (CK), 1:5 (C1), 1 : 2 (C2), and 1 : 1 (C3) were selected. Each treatment was repeated 3 times for a total of 12 trial plots. The area of each test plot was 4 m^2 (2×2 m). The mixing depth of the soft rock and sand in the test plot was designed to be 0 - 30 cm, simulating the field conditions and 30 - 70 cm was completely filled with sand. The experimental field was planted with corn (Jincheng 508) - wheat (Xiaoyan 22), which was made by two crops a year and all of which were artificially sown. The types of fertilizers tested in the experimental field were urea (including N 46.4%), diammonium phosphate (including N 16%, containing P_2O_5 44%) and potassium sulfate (including K_2O 52%). The amount applied for the above mentioned 3 fertilizers were 255 kg/hm^2 (N), 180 kg/hm^2 (P_2O_5) and 90 kg/hm^2 (K_2O), respectively.

After harvesting the wheat from the experimental fields in May 2018, samples of 0-30 cm soil layers from 5 randomly selected points in each plot were collected and the samples were mixed together. The composite soil samples were sieved through a 2 mm sieve to remove plant and animal debris. Later on the sample was divided into two parts, one part was placed in a 4°C refrigerator for mineralization culture test and 2nd part was naturally air-dried ground screened with 0.25 mm screen for the determination of organic carbon.

The mineralization culture test was carried out by the alkali absorption method (Guo *et al.* 2019). Organic carbon was determined by potassium dichromate-concentrated sulfuric acid external heating method (Nelson and Sommers 1996).

All the data were sorted and graphed using EXCEL 2019, and analysis of variance and multiple comparisons were performed using SPSS 19.0. Pearson correlations were used to compare mineralization parameters and wheat yield.

Results and Discussion

The organic carbon content of CK treatment was 2.65 g/kg, and there was no significant difference between the organic carbon content of C1, C2 and C3 treatment and that of CK treatment ($p > 0.05$, Fig. 1). With the increase of the proportion of soft rock, the soil organic carbon content showed a trend of decreasing first and then increasing. The content of organic carbon treated by C3 was the highest in C1, C2 and C3 treatments. The mineralization rate of organic carbon in soils with different mixing ratios of soft rock and sand showed a dynamic downward trend with the cultivation time (Fig. 2), which conforms to the logarithmic function relation y = a + b ln(x) ($p < 0.01$) (Table 1). The mineralization rates of organic carbon in CK and C3 treatments reached the peak on the 3rd day of incubation and the rates were 29.28 and 60.26 mg/kg/d, respectively. Because the soil microenvironment was still at the beginning of the reaction, it was also possible that the compound soil organic carbon in the initial stage of mineralization was mostly in the form of complex compounds, and there were few small molecular compounds that were easily decomposed. At this time, the microorganism needs to simplify the complex compound before it can be absorbed and utilized, so the respiratory rate showed a rapid rising phase in the initial stage (Li 2000). The mineralization rates of organic carbon in C1 and C2 treatments reached the peak on the 5th and 2nd of incubation time, which were 60.98 and 53.78 mg/kg/d, respectively. All treatments began to decline slowly after the 8th

day, and the organic carbon mineralization rate at the 30th day of culture decreased significantly by 89.36 (CK), 86.72 (C1), 84.97 (C2) and 84.00% (C3). The mineralization rate of all treatments can be divided into two stages of change, the rapid change phase (1 - 8 days) and the slow decline phase (8 - 30 days). The reason was that in the early mineralization stage, the organic matter mainly decomposed by soil microbes derived from animal (rotifers, nematodes, earthworms, mollusks and various arthropods, etc.) and plant residues (roots, stubble, dead leaves, etc.) and
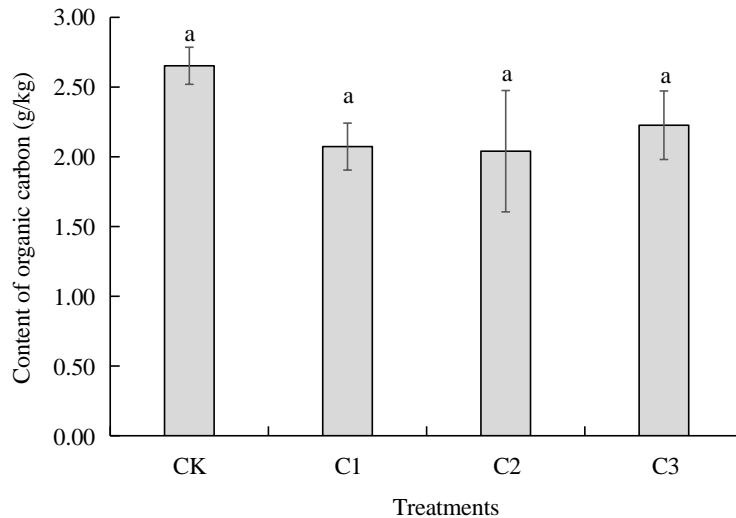

Fig. 1. Organic carbon content of compound soils in different proportions of soft rock and sand. Different letters above the bars mean significant difference (at 0.05 level) between treatments. CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1.
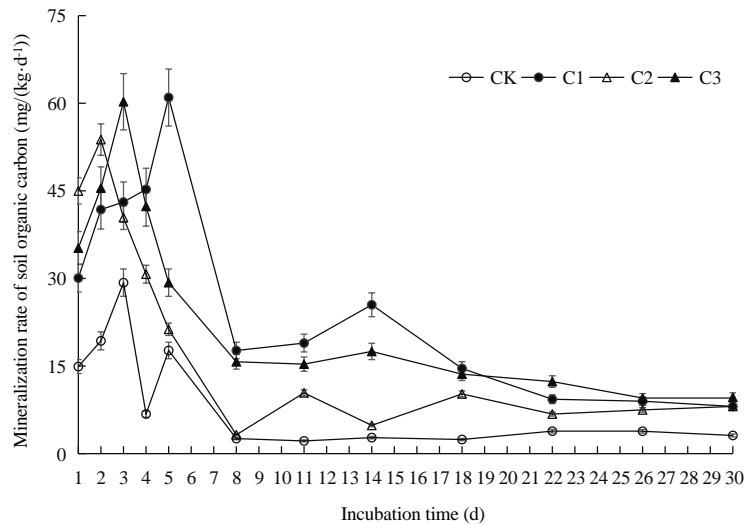

Fig. 2. Organic carbon mineralization rate of compound soils in different proportions of soft rock and sand. CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1.

their secretions. At this time, there were a large number of active organic substances such as sugars and proteins which were easily decomposed in the soil. This condition provided abundant carbon sources and nutrients for soil microorganisms to promote microbial activity. With the prolongation of culture time, the active organic components underwent their easy decomposition into the soil and were gradually used up by the microorganisms. However, the remaining components such as lignin and cellulose were difficult to be decomposed and to be utilized by the microorganisms. Therefore, the mineralization rate showed a trend from fast to slow, and the cumulative mineralization showed a cumulative trend of gradual decrease in release intensity (Lu *et al.* 2017, Li *et al.* 2018b).

Table 1. Regression equation of soil organic carbon mineralization rate and cumulative mineralization under different compounding ratios.

Index	Treatment	Regression equation	r
Mineralization rate	CK	$y = -6.023\ln(x) + 21.376$	0.7313**
	C1	$y = -11.34\ln(x) + 50.219$	0.7176**
	C2	$y = -14.48\ln(x) + 49.806$	0.8907**
	C3	$y = -12.63\ln(x) + 51.362$	0.8244**
Cumulative mineralization	CK	$y = 40.447\ln(x) + 13.027$	0.9855**
	C1	$y = 171.1\ln(x) - 42.481$	0.9841**
	C2	$y = 90.141\ln(x) + 36.229$	0.9844**
	C3	$y = 150.08\ln(x) - 16.144$	0.9849**

CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1. y: CO_2 production rate, mg/(kg·d^{-1}); x: Incubation day, d; [**] Means significant correlation at 0.01 level.

The relationship between the cumulative mineralization of organic carbon and the incubation time in different proportions of soft rock and sand was also in accordance with the logarithmic function relationship $y = a + b \ln(x)$ ($p < 0.01$) (Fig. 3 and Table 1). The results showed that with the extension of incubation time, the accumulation intensity of organic carbon and mineralization rate decreased gradually. It was evident by a decrease in the release rate of the CO_2 and the result is quite consistent with the study of Zhang *et al.* (2011). During the whole culture period, the cumulative mineralization of organic carbon in C1 treatment was the highest, followed by C3 and C2 treatments. On the otherhand, CK treatment had the lowest accumulation mineralization, with significant difference among all treatments (F = 26.54, $p < 0.01$). After incubation for 30 days, the cumulative mineralization of organic carbon treated by CK was 163.33 mg/kg. The cumulative mineralization of organic carbon treated by C1, C2 and C3 increased significantly by 249.78, 130.77 and 229.83%, respectively (Table 2). However, there was no significant difference in the cumulative mineralization of organic carbon between C1 and C3 treatments, but they were significantly higher than C2 treatment. The cumulative mineralization rate of soil organic carbon in different compound ratio of soft rock and sand can reflect the strength of the carbon fixation capacity of the new compound soil. The higher the ratio, the weaker the carbon sequestration capacity of the soil, and vice versa (Sisti *et al.* 2004). It can be seen from Fig. 4 that the cumulative mineralization rate of soil organic carbon did not show significant difference in the two treatments of C1 and C3 after 30 days of culture ($p > 0.05$). But both were significantly higher

than C2 treatment and CK treatment was the lowest. It can be seen that the cumulative mineralization rate of organic carbon treated by the three soft rock compound ratios was significantly higher than that of CK treatment and the effect of C2 treatment was better in the compound ratios treatment. Because the age of soil formation was only two years and the soft rock
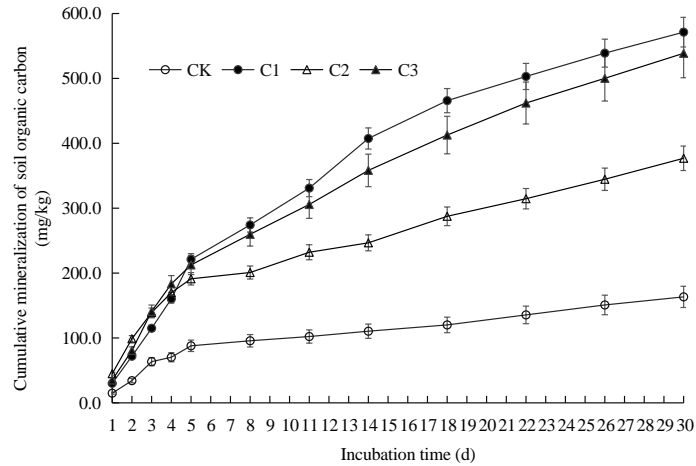

Fig. 3. Organic carbon cumulative mineralization of compound soils in different proportions of soft rock and sand. CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1:5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1.
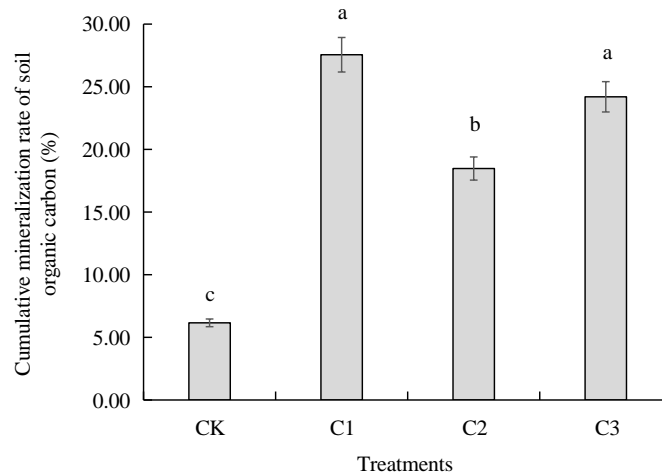

Fig. 4. Cumulative mineralization rate of soil organic carbon under different compound ratios during the 30 days of incubation. CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1. Different letters above the bars mean significant difference (at 0.05 level) between treatments.

was also a clay mineral (Wang *et al*. 2013) with more silt and clay particle content but it takes a certain time to decompose in water. The CK treatment was based on pure sand with uniform texture and less disturbance by humans (Arribas and Tortosa 2003). With the increase of the

proportion of soft rock, the gap between the soft rock and the sand was large. As a result the structure was loose, and the nutrient content migrates to the bottom layer along with rainfall and irrigation. This had resulted in lower organic carbon content in the compound soil. The soft rock itself was rich in more mineral elements and organic carbon with enhanced aeration. It had promoted the activity and decomposition ability of the microorganisms, therefore showed the lowest cumulative mineralization rate of CK treatment (She *et al.* 2015, Wang *et al.* 2017).

There were significant differences between the parameters of the kinetic equations of organic carbon mineralization in the soil of different proportions of soft rock and sand and the first-order kinetic equation $C_t = C_0 (1 - e^{-kt})$ was used for parameter fitting ($p < 0.01$, Table 2). The potential mineralizable organic carbon (C_0) content is consistent with the change trend of organic carbon accumulation mineralization (C_t). The k values of CK and C2 treatments were significantly higher than those of C1 and C3 treatments. This indicates that the decomposition of organic carbon active components in CK and C2 treatments was faster and the turnaround time was shorter. It may be due to the application of chemical fertilizers in this experiment which increases the inorganic nitrogen content of soil such as nitrate nitrogen and ammonium nitrogen. All these reacts with compounds like lignin or phenol present in the soil, so that C1 treatment and C3 treatment of organic carbon have lower decomposition (Jenkinson *et al.* 1985, Liu *et al.* 2017). The trend of $T_{1/2}$ was opposite to that of k. Compared to C_0/SOC treated by CK, decomposition of C1, C2 and C3 treatments increased by 25.66, 11.16 and 20.21 percentage points ($p < 0.05$), respectively and C2 treatment decreased significantly by 14.50 and 9.06 percentage points compared to C1 and C3 treatments. It can be seen that the C_0/SOC was consistent with the trend of the cumulative mineralization rate of soil organic carbon.

Table 2. Cumulative mineralization of SOC after the 30 days of incubation and parameters of its kinetic equations.

Treatments	C_t (mg/kg)	C_0 (mg/kg)	k (d^{-1})	$T_{1/2}$	C_0/SOC (%)	R^2
CK	163.33 c	146.75 c	0.1380 a	5.02 b	5.53 c	0.931**
C1	571.29 a	646.69 a	0.0698 b	9.93 a	31.19 a	0.9958**
C2	376.92 b	340.48 b	0.1321 a	5.25 b	16.69 b	0.9249**
C3	538.72 a	573.15 a	0.0771 b	8.99 a	25.74 a	0.9864**

CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1. C_t for amount of organic carbon cumulative mineralization, C_0 for amount of potential mineralizable organic carbon, k for constant of organic carbon mineralization rate, $T_{1/2}$ for half turnover period, C_0/SOC for ratio of potential mineralizable organic carbon to total organic carbon in compound soil. Values followed by different letters in the same column mean significant difference at 0.05 level between treatments, **indicates a extremely significant level of 1%.

The results of wheat yield measurement after harvest showed that the the average wheat yield in all treatments was C2 > C1 > C3 > CK (Fig. 5). Compared with CK treatment, C3 treatment showed no significant difference ($p > 0.05$), while C1 and C2 treatments increased significantly by 6.24 and 12.84% ($p < 0.05$). Pearson correlation analysis between wheat yield and soil organic carbon mineralization parameters showed no significant difference ($p > 0.05$, Table 3). It might be that crop yields are directly related to available nutrients and trace elements in the soil under the action of microorganisms. However, both yield and mineralization results indicated that C2 treatment had a significant effect on the accumulation of organic carbon and the increase of crop

yield. With regard to the intrinsic connection mechanism between soil and plant body, further research can be carried out in the future, such as research on microbial diversity, soil microstructure, plant metabolism process, and organic inorganic colloid, etc.
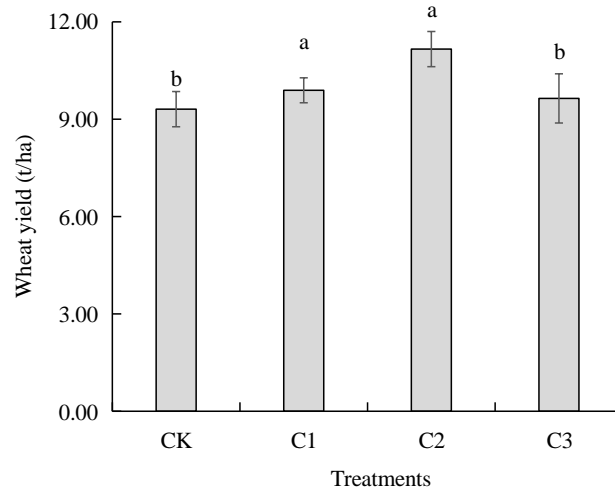

Fig. 5. Harvest yield of wheat with soft rock and sand compound soil. CK: The volume ratio of soft rock to sand is 0 : 1; C1: The volume ratio of soft rock to sand is 1 : 5; C2: The volume ratio of soft rock to sand is 1 : 2; C3: The volume ratio of soft rock to sand is 1 : 1. Different letters above the bars mean significant difference (at 0.05 level) between treatments.

Table 3. Pearson correlation coefficients between mineralization parameters and wheat yield.

Index	SOC (g/kg)	C_t (mg/kg)	C_0 (mg/kg)	C_r(%)	k (d^{-1})	$T_{1/2}$	C_0/SOC (%)
WY (t/ha)	0.7226	0.1500	0.0300	0.2427	0.2596	0.2769	0.1049

WY for amount of wheat yield, SOC for amount of soil organic carbon, C_t for amount of organic carbon cumulative mineralization, C_0 for amount of potential mineralizable organic carbon, C_r for amount of cumulative mineralization rate, k for constant of organic carbon mineralization rate, $T_{1/2}$ for half turnover period, C_0/SOC for ratio of potential mineralizable organic carbon to total organic carbon in compound soil.

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