The mineralization characteristics of organic carbon and particle composition analysis in reconstructed soil with different proportions of soft rock and sand

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The organic carbon mineralization process reflects the release intensity of soil CO_2. Therefore, the study of organic carbon mineralization and particle composition analysis of s oft rock and sand comp ound soil can provide technical support and a theoretical basis for soil organic reconstruction (soil structure, materials and biological nutrition) . Based on previous research, four treatments were selected: CK (soft rock:sand=0:1), C1 (soft rock:sand=1:5), C2 (soft rock:sand=1:2) and C3 (soft rock:sand=1:1), respectively. Specifically, we analyzed the organic carbon mineralization process and soil particle composition by lye absorption, laser granulometer , and scanning electron microscope. The results showed that there was no significant difference in organic carbon content between C1, C2 , and C3 treatments, but they were significantly higher than in the CK treatment (P < 0.05). The organic carbon mineralization rate in each treatment accords with a logarithmic function throughout the incubation period (P < 0.01), which can be divided into a rapid decline phase in days 1 to 11 followed by a steady decline phase in days 11 to 30. The cumulative mineralization on the 11th day reached 54.96%-74.44% of the total mineralization amount. At the end of the incubation, the cumulative mineralization and potential mineralizable organic carbon content of the C1, C2 and C3 treatments were significantly higher than those of the CK treatment . T he cumulative mineralization rate was also the lowest in the C1 and C2 treatment. The turnover rate constant of soil organic carbon in each treatment was significantly lower than that of the CK treatment, and the residence time increased. With the increase of volume fraction of soft rock, the content of silt and clay particles increase d gradually, the texture of soil change d from sandy soil to sandy loam, loam , and silty loam, respectively. With the

increase of small particles, the structure of soil appear ed to collapse when the volume ratio of soft rock was 50%. A comprehensive mineralization index and scanning electron microscopy analysis, when the ratio of soft rock to sand volume was 1:5-1:2, this can effectively increase the accumulation of soil organic carbon. Then, the distribution of soil particles was more uniform, the soil structure was stable (not collapsed) , and the mineralization level of unit organic carbon was lower. Our research results have practical significance for the large area popularization of soft rock and sand compound technology.

1   **The mineralization characteristics of organic carbon and particle composition analysis in**

2   **reconstructed soil with different proportions of soft rock and sand**

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18   Short title: Soil organic carbon mineralization

23 **Abstract**

24 The organic carbon mineralization process reflects the release intensity of soil CO_2. Therefore, the study of

25 organic carbon mineralization and particle composition analysis of soft rock and sand compound soil can

26 provide technical support and a theoretical basis for soil organic reconstruction (soil structure, materials

27 and biological nutrition). Based on previous research, four treatments were selected: CK (soft

28 rock:sand=0:1), C1 (soft rock:sand=1:5), C2 (soft rock:sand=1:2) and C3 (soft rock:sand=1:1),

29 respectively. Specifically, we analyzed the organic carbon mineralization process and soil particle

30 composition by lye absorption, laser granulometer, and scanning electron microscope. The results showed

31 that there was no significant difference in organic carbon content between C1, C2, and C3 treatments, but

32 they were significantly higher than in the CK treatment ($P < 0.05$). The organic carbon mineralization rate

33 in each treatment accords with a logarithmic function throughout the incubation period ($P < 0.01$), which

34 can be divided into a rapid decline phase in days 1 to11 followed by a steady decline phase in days 11 to

35 30. The cumulative mineralization on the 11th day reached 54.96%-74.44% of the total mineralization

36 amount. At the end of the incubation, the cumulative mineralization and potential mineralizable organic

37 carbon content of the C1, C2 and C3 treatments were significantly higher than those of the CK treatment.

38 The cumulative mineralization rate was also the lowest in the C1 and C2 treatment. The turnover rate

39 constant of soil organic carbon in each treatment was significantly lower than that of the CK treatment, and

40 the residence time increased. With the increase of volume fraction of soft rock, the content of silt and clay

41   particles increased gradually, the texture of soil changed from sandy soil to sandy loam, loam, and silty

42   loam, respectively. With the increase of small particles, the structure of soil appeared to collapse when the

43   volume ratio of soft rock was 50%. A comprehensive mineralization index and scanning electron

44   microscopy analysis, when the ratio of soft rock to sand volume was 1:5-1:2, this can effectively increase

45   the accumulation of soil organic carbon. Then, the distribution of soil particles was more uniform, the soil

46   structure was stable (not collapsed), and the mineralization level of unit organic carbon was lower. Our

47   research results have practical significance for the large area popularization of soft rock and sand compound

48   technology.

49

50   **INTRODUCTION**

51   The farmland soil organic carbon pool plays an important role not only in the process of global carbon

52   circulation but also as the most important material base for soil fertility (Pan *et al.*, 2009), and has a decisive

53   role among others in the maintenance of cultivated land productivity, the prevention and treatment of soil

54   erosion, the spatial and temporal variation of soil respiration, and its stability (Tommaso *et al.*, 2018). The

55   soil organic carbon pool in terrestrial ecosystems is about three times that of the plant carbon pools (Lal,

56   2004). The organic carbon exchanged between soil and atmosphere accounts for about 2/3 of the total

57   carbon storage of surface ecosystems, which slightly changed in recent years because of the impact of

58   greenhouse gas emissions (Lal, 2004). Soil organic carbon mineralization is an important part of the carbon

59   cycle in terrestrial ecosystems. The change in land resources by human activities causes changes in

60   atmospheric CO_2 concentration through the effects on terrestrial ecosystems which in turn affects the carbon

61   cycle and the climate change process (Stumpf *et al.*, 2018). Therefore, the research on soil carbon cycle by

62 human activities has attracted much attention in recent years and has become the core issue of

63 multidisciplinary research (Feng *et al.*, 2006; Schmitz *et al.*, 2017; Zhang *et al.*, 2018).

64 Soil organic carbon mineralization is a process in which organic substances are decomposed into

65 inorganic substances by microbial degradation, providing nutrients for crop growth, and releasing

66 greenhouse gases such as CO_2 (Dai *et al.*, 2017; Guo *et al.*, 2018). Current studies have shown that arid and

67 semi-arid regions account for 41% of the global land area, carrying 38% of the human population, and

68 which are sensitive to global climate change and human activities (Zhou and Zhang, 2009). Experts call it

69 the arid and semi-arid areas of Shaanxi, Shanxi, Inner Mongolia and other arid areas "Earth Environment

70 Cancer", since these important soil resources exhibit serious soil and water loss, loss of soil texture, low

71 nutrient content and poor structure. This can be seen as a geographical hazard of the soft rock and sand

72 areas and it determines the urgency and difficulty of ecological restoration in the region (Wang *et al.*, 2007).

73 Han *et al.* (2012) studied the structure and physicochemical properties (including capillary porosity,

74 saturated hydraulic conductivity, organic matter, water-stable aggregates, mineral composition, and crop

75 yield) of soft rock and sand and realized that the two soil forms can be mixed into different proportions to

76 form a "new soil". They also suggested that the optimal compounding ratio for crop growth ranged between

77 1:5 and 1:1 (soft rock: sand). Presently, the technology of compounding of soft rock and sand into soil is

78 widely used, and the newly added cultivated land amounts to 1573 ha, which realized the resource

79 utilization of soft rock and improved the regional ecological environment (Han *et al.*, 2012). She *et al.*

80 (2015) studied the nutrient content and hydraulic parameters of the soft rock and sand compound soil, and

81 proposed that the fertilizer retention performance of the compound soil can be effectively improved with

82 an increase of the soft rock content, whereas the available nutrient content can be improved with sufficient

83   water. Wang (2016) mixed sand and soft rock to a certain proportion forming a new type of soil, analyzed

84   its textural changes and biochemical indexes of crops, and discussed the soil texture changes from sand to

85   silt loam as the proportion of soft rock increased. Moreover, the photosynthesis rate of crops and the activity

86   indexes of antioxidant enzymes increased at the beginning and then decreased. However, considering the

87   present global warming, we should not only improve the utilization rate of waste resources but also maintain

88   the sustainable development of ecological environment. The issue of greenhouse gas emissions from the

89   compounded soil is an area which has not yet been considered by researchers. The carbon pool balance

90   depends not only on carbon emissions but also on carbon sequestration. Therefore, the carbon source or

91   sink of the composite soil also needs to be further studied.

92   The texture of soft rock is loose because of the complementary nature of its components: the large

93   amount of montmorillonite is strongly hydrophilic with a high adsorption potential whereas the aeolian

94   sandy soil is leaking water and fertilizer (Sun and Han, 2018). Research on the soft rock and sand compound

95   soil in the early stage showed that the increase of the ratio of soft rock to sand can effectively increase the

96   capillary porosity and decrease the water infiltration coefficient of the aeolian sandy soil (Li *et al.*, 2018a;

97   Shen *et al.*, 2013; Wang *et al.*, 2017; Zhang *et al.*, 2016). The texture was also improved to a certain extent

98   from sand to sandy loam (Wang *et al.*, 2017). The results of the mechanical test (conditions: the loading

99   confining pressure was set to 50, 100, 200 kPa; the moisture content of the compound soil was 14%; the

100   dry density was 1.6 g cm^{-3}) for different mixing ratios of soft rock and sand using a dynamic three axis

101   showed that the macroscopic mechanics exhibited a strain-hardening phenomenon with non-linear

102   characteristics (Lei *et al.*, 2018). After adding soft rock, the final water content of the improved soil was

103   significantly higher than that of the aeolian sandy soil, which was beneficial for the maintenance of water

104   and fertilizers. The results also indicated that the toxic effect of lead in aeolian sandy soil is effectively and

105   proportionally reduced by the amount of soft rock added (Li *et al.*, 2018a). However, the research only

106   focused on the hydraulic properties, fertility, and the adsorption of the soft rock and aeolian sandy soil

107   during the early stage, lacking research on the carbon source/carbon sink effect of the compound soil.

108   Therefore, the purpose of this study is to (1) clarify the carbon mineralization strength of the compound

109   soil in different proportions of sandstone and sand; (2) understand the microstructure and particle

110   composition of the compound soil; and (3) clarify the carbon fixation effect of different proportions of

111   mixed soil and provide a basis for a sustainable development of the regional ecology. We hypothesized that

112   (1) the addition of different proportions of soft rock can effectively increase the soil organic carbon and

113   mineralized carbon content, acting as a carbon sink when the volume fraction of soft rock is less than 50%;

114   and (2) with the increase of volume fraction of soft rock, the soil fine particles increase, changing the texture

115   from sand to silt loam.

116

117   **MATERIALS & METHODS**

118   **Overview of the test site**

119   The experimental plot was set up at the Fuping County pilot test base from the Shaanxi provincial land

120   engineering technology research institute. Fuping County (108°57′-109°26′E,34°42′-35°06′N) lies at the

121   transition zone between the Guanzhong plain and the northern Shaanxi plateau that belongs to the gully

122   region of the Weibei Loess Plateau. The terrain is high in the north and low in the south. It slopes from the

123   northwest to the southeast. The elevation in the territory is between 376-1421 m. The area belongs to the

124   continental monsoon warm zone with a semi-arid climate. The annual total radiation is 5187 MJ m^{-2}, the

125   annual average sunshine hours are about 2389 h with an annual average temperature of 13 ℃, and an annual

126   average precipitation of 527 mm. The interannual variation of precipitation is high, and the annual

127   precipitation coefficient of variation (CV) reaches 21%.

128

129   **Experiment design**

130   The field test plot was set to simulate the land condition of the soft rock and sand mixed layer in the Mu Us

131   sandy land. The experimental plot layers were set to a mixture of soft rock and sand at 0-30 cm, and a layer

132   of aeolian sandy soil between 30-70 cm. The soft rock and sand were taken from the Daji Han Village,

133   Xiaoji Han township, Yuyang district, and Yulin city. The minerals in the soft rock mainly include quartz,

134   montmorillonite, feldspar, calcite, illite, kaolinite, and dolomite. The main chemical constituents of soft

135   rock are SiO_2 (65% by mass), Al_2O_3 (14% by mass), Fe_2O_3 (12% by mass) and CaO (9% by mass). The

136   mineral in the sand is mainly quartz (SiO_2) with a mass fraction of about 82%. The remaining minerals are

137   mainly feldspar (10% by mass), kaolinite (4% by mass), calcite (2% by mass), and amphibole (2% by mass).

138   The organic carbon content of soft rock and sand are 2.00 g kg^{-1} and 0.63 g kg^{-1}, respectively.

139   The analysis was performed in 2009, and four treatments of soft rock and sand with the different

140   volume ratios of 0:1 (CK), 1:5 (C1), 1:2 (C2), and 1:1 (C3) were selected. Each treatment was repeated 3

141   times with a total of 12 trial plots and randomly distributed. Each plot area covered 2 m×2 m (= 4 m²). For

142   uniformity of factors such as illumination and micro-topography, the test plot was arranged from south to

143   north in a "one" shape with a depth of the soil layer of 30-40 cm (Fig. 1), whereas the mixing depth of the

144   soft rock and sand in the test plot was designed in the first 30 cm, simulating the field conditions. The layer

145   between 30-70 cm was completely filled with sand. The experimental field crops were corn (Jincheng 508)

146 and wheat (Xiaoyan 22), thus providing two different crops a year, all of which were artificially sown.

147 Different types of fertilizers were tested in the experimental field consisting of urea (including N 46.4%),

148 diammonium phosphate (containing N 16% and P_2O_5 44%), and potassium sulfate (including K_2O 52%).

149 The amount of fertilizer applied was 255 kg ha^{-1} (N), 180 kg ha^{-1} (P_2O_5) and 90 kg ha^{-1} (K_2O). All treatments

150 were similarly applied. All phosphate and potassium fertilizers were used as base fertilizers, 65% of

151 nitrogen fertilizers were used as base fertilizers, and 35% were combined with the irrigation water to be

152 applied at the booting stage. Wheat planting time is generally in the middle and late October, whereas the

153 corn planting time is in the middle and late May. One to two days before sowing, the three fertilizers were

154 weighed according to the required amount of each plot, evenly spread on the soil surface, and then properly

155 ploughed to mix the fertilizer with the topsoil.

156

157 **Soil sample collection**

158 After the wheat harvest in May 2018, five uniformly distributed samples from the 0-30 cm soil layer of

159 each plot were collected to form a mixed sample. Animals and plant residues were removed from the

160 collected soil samples. Afterwards, the samples were sieved through a 2 mm sieve and divided into two

161 parts, one part was placed in a 4 °C refrigerator for the mineralization incubation test whereas the other part

162 was naturally air-dried, ground and then sieved through a 1 mm and a 0.149 mm screen for a subsequent

163 scanning electron microscopy analysis to determine the texture and organic carbon.

164

165 **Determination method**

166 The mineralization incubation test was carried out by the Alkali Absorption Method (Dai *et al.*, 2017; Ribeiro *et*

167   *al.*, 2010; Zibilske 1994). For this, the soil placed in the refrigerator at 4℃ was weighed and 30 g transferred

168   into a beaker, set to a field water holding capacity of about 60%, and then pre-incubated in the incubator at 25℃

169   for 5 days. The purpose was to restore microbial activity and adapt to the current incubation environment. Then

170   the lye and the beaker filled with the soil were transferred into an incubation bottle, sealed, and incubated in the

171   dark. The lye was then analyzed by titration with diluted hydrochloric acid at the days 1, 2, 3d, 4, 5, 8, 11, 14,

172   18, 22, 26, and 30, respectively (borax (0.05 mol L^{-1}) was used for calibration before each titration). At each

173   titration, 2 mL of 1 mol L^{-1} $BaCl_2$ solution was added to the soil-filled beaker together with 2 drops of

174   phenolphthalein indicator. Water was added to the soil to a constant weight each time the lye absorption cup was

175   changed.

176   Organic carbon was determined by the potassium dichromate-concentrated Sulfuric Acid External

177   Heating method (Nelson and Summers, 1996). The texture was measured using a Malvern laser particle

178   size analyzer (MS2000, Malvern, UK). The soil sample after the 1 mm sieving was cured by epoxy resin,

179   first coarsely then artificially ground, and polished by a sander to make the surface smooth. Thus prepared,

180   a microsample with a diameter of 5 mm and a height of 3 mm was obtained. The dried sample was subjected

181   to gold plating, and scanning was performed by a scanning electron microscope (FEI Q45, USA) using a

182   voltage of 25 kV in an "S" type and a magnification of 1000 times.

183

184   **Data Processing and Analysis**

185   The cumulative amount of soil organic carbon mineralization refers to the total amount of soil CO_2 released

186   from the beginning of cultivation to a certain time point. It can be fitted by the first-order kinetic equation

187   using the Origin drawing software 2017, i.e., $C_t = C_0 (1-e^{-kt})$ (Ribeiro *et al.*, 2010),

188 $$C_t = C_0(1 - e^{-kt})$$ (1)

189   Where C_t is the accumulated mineralization amount of soil organic carbon in mg kg^{-1} after time t; C_0

190 is the soil potential mineralized organic carbon in mg kg^{-1}; k is the constant of organic carbon mineralization

191 rate, d^{-1}; t is the number of days of cultivation, and d the half-turn period $T_{1/2} = \ln 2/k$.

192   Texture data was classified using the TriangleVB software. All data was sorted and graphed using

193 EXCEL 2019, and the analysis of variance and multiple comparisons were performed using SPSS 19.0.

194

195 **RESULTS**

196 **Compound soil organic carbon**

197 The organic carbon content of aeolian sandy soil can be significantly improved by adding different

198 proportions of soft rock (Fig. 2). The organic carbon content in the CK treatment was 2.02 g kg^{-1}. The

199 organic carbon content in the C1, C2, and C3 treatments was significantly increased compared to that of

200 the CK treatment (P < 0.05) with increases of 110%, 77% and 119%, respectively. With the increase of the

201 proportion of soft rock, the soil organic carbon first increased, then decreased, to continue to increase again.

202 The organic carbon content in the C1 treatment was 4.24 g kg^{-1}, and the organic carbon content of C2 and

203 C3 treatment decreased and increased by 16% and 4%, respectively. Though there was an increase by 24%

204 in the C3 treatment compared to the C2 treatment, there was no significant difference (P > 0.05).

205

206 **Compound soil organic carbon mineralization rate**

207 The mineralization rate of organic carbon in soils with different mixing ratios of soft rock and sand showed

208 a logarithmic, dynamic downward trend with the cultivation time with a relation of y = a + b ln(x) (P <

209 0.01) (Fig. 3, Table 1). The logarithm function does not introduction of mineralization potential and other

210 parameters, which reflects the pure digital variation law, indicating that the data trend is better. The

211 mineralization rates of organic carbon in the CK and C3 treatments reached their peaks compared to day 1

212 on day 3 of incubation with 49.6 mg kg^{-1} d^{-1} (76%) and 66.1 mg kg^{-1} d^{-1} (37%), respectively. The

213 mineralization rate of organic carbon decreased rapidly after day 3 slowing down its decline after day 11.

214 The organic carbon mineralization rate at 30 days of cultivation was 3.4 mg kg^{-1} d^{-1} (CK) and 13.5 mg kg^{-}

215 ^{1} d^{-1} (C3), respectively, which indicates a decrease by 93% and 80% compared to day 3. However, the

216 organic carbon mineralization rate in the C1 and C2 treatment exhibited its maximum on the first day of

217 incubation with 58.7 mg kg^{-1} d^{-1} and 43.5 mg kg^{-1} d^{-1}, respectively. The mineralization rate in the C1 and C

218 2 treatments rapidly declined until day 11, after that this decline slowed down. The mineralization rate on

219 the day 30 was 83% and 81.68% lower than that of the first day, respectively. Taken together, the average

220 mineralization rate in the C3 treatment was the highest in all compound ratio treatments, followed by the

221 C1 and the C2 treatment, whereas the CK treatment exhibited the lowest mineralization rate. The

222 mineralization rate of all treatments can be divided into two stages: namely a rapid decline (1-11 days) and

223 steady decline (11-30 days). In general, the CO_2 production rate changed greatly during the rapid decline

224 phase, whereas the mineralization rate between all treatments was consistent during the steady decline

225 phase.

226

227 **Cumulative mineralization of compound soil organic carbon**

228 The relationship between the cumulative mineralization of organic carbon and the incubation time in

229 different proportions of soft rock and sand demonstrated a logarithmic function relationship $y = a + b \ln(x)$

230   (P < 0.01) (Fig. 4, Table 1). The results showed that the organic carbon accumulation mineralization

231   decreased gradually with the incubation time, which indicates that the CO_2 release rate decreased. During

232   the whole incubation period, the cumulative mineralization of organic carbon was significantly the highest

233   in the C3 treatment, followed by the C1 and C2 treatments, whereas the CK treatment had the lowest

234   mineralization accumulation (F = 26.54, P < 0.01). After incubation for 30 days, the cumulative

235   mineralization of organic carbon in the CK treatment was 274 mg kg^{-1}. The cumulative mineralization of

236   organic carbon treated by C1, C2 and C3 increased significantly by 88%, 59%, and 193% as compared to

237   CK, respectively (Table 2). There was no significant difference in the cumulative mineralization of organic

238   carbon between the C1 and C2 treatments. Compared to the C1 and C2 treatment, the cumulative

239   mineralization of organic carbon in C3 treatment was significantly increased by 55% and 84%, respectively.

240

241   **Cumulative mineralization rate of organic carbon in compound soil**

242   The cumulative mineralization rate of soil organic carbon in the different compound ratios of soft rock and

243   sand can reflect the strength of the carbon fixation capacity in the new compound soil. The higher the ratio,

244   the weaker the carbon sequestration capacity of the soil, and vice versa. Fig. 5 shows that the cumulative

245   mineralization rate of soil organic carbon in the three treatments of CK, C1, and C2 did not reach a

246   significant difference after 30 days of incubation (P > 0.05). In our analysis, C1 exhibited the lowest

247   cumulative mineralization rate in the three treatments. The cumulative mineralization rate of organic carbon

248   in the C3 treatment was 18%, which was significantly increased by 4.6, 6.0 and 6.0 percentage points as

249   compared to CK, C1 and C2, respectively. Compared to the C1 treatment, the cumulative mineralization

250   rate of organic carbon in CK, C2, and C3 treatments increased by 1.4, 0.1 and 6.0 percentage points,

251   respectively.

252

253   **Fitting parameters of organic carbon mineralization in compound soil**

254   There were significant differences between the parameters of the kinetic equations of organic carbon

255   mineralization in the treatments with different proportions of soft rock and sand. Indeed, the first-order

256   kinetic equation $C_t = C_0 (1-e^{-kt})$ was used for parameter fitting (P < 0.01) and introduced two parameters of

257   mineralization rate constant and potential mineralizable carbon. The potential mineralizable organic carbon

258   (C_0) content of the CK treatment was 257 mg kg^{-1}, and the C_0 values in C1, C2 and C3 treatment were

259   significantly increased by 104%, 88%, and 264%, respectively (P < 0.05). There was no significant

260   difference between the C1 and C2 treatments (Table 2), whereas the C3 treatment exhibited significantly

261   increased C_0 values with 78% and 93% compared to the C1 and C2 treatments. The k-values (the organic

262   carbon mineralization rate constant) of the C1, C2, and C3 treatments were lower than those of the CK

263   treatment though not significantly. The trend of $T_{1/2}$ (half-turn period) was opposite to that of the k-values,

264   indicating that the addition of different proportions of soft rock reduced the mineralization rate constant of

265   organic carbon and increased the retention time of organic carbon in the soil. The C_0/SOC (SOC: soil

266   organic carbon) of the CK treatment was 13%. Taken together, the C1, C2, and CK treatments were not

267   significantly different to each other whereas the C3 treatment was significantly increased by 8% compared

268   to the CK treatment.

269

270   **Compound soil microstructure**

271   The microstructure of the compound soil provides us some information about the corresponding soil

272   structure. Using the scanning electron microscope (SEM) we observed irregular shapes of sand grains.

273   Though the degree of grinding was high, there were no sharp edges and angles in the CK treatment (Fig. 6-

274   a). With the increase of the volume fraction of the soft rock (C1, C2, C3) (Fig. 6-b, c, and d), the overall

275   structure of the composite soil showed no obvious change but the filling of fine particles increased

276   gradually. As the volume fraction of small particles gradually increased, the distance between the small and

277   large particles increased more than the one between the large particles. When the content of soft rock

278   reached 50% (C3, Fig. 6-d), due to the increase of the specific surface area of the small particles, the large

279   particles were not enough to support the soil structure, which entailed a collapse of the soil mass.

280

281   **Compound soil mechanical composition**

282   In the CK treatment, the content of sand was 87%. With the increase of the proportion of soft rock, the sand

283   content gradually decreased, which was for the C1, C2, and C3 treatment as compared to the CK treatment

284   33, 42 and 46 percentage points, respectively (P < 0.05). The silt content increased gradually with the

285   increase of soft rock, which was for the C1, C2, and C3 treatment an increase of 29, 35, and 39 percentage

286   points, respectively (P < 0.05). The clay content of the CK treatment was 2.3%. With the increase of volume

287   fraction of soft rock, the clay content in the C1, C2 and C3 treatments increased by 4.5, 7.0 and 7.2

288   percentage points, respectively, as compared to the CK treatment (P < 0.05). Thus, the increase of the clay

289   component was smaller than that of silt. There were no significant differences between the three C1, C2,

290   and C3 treatments. Taken together, with the increased volume fraction of soft rock, the texture of compound

291   soil gradually changed from sandy soil to sandy loam, loam, and silty loam (Fig. 7).

292

293 **DISCUSSION**

294 Soil organic carbon mineralization is an important biochemical process in soil, which is directly related to

295 the release and supply of soil nutrient elements, CO_2 gas emissions, and soil quality maintenance (Ross *et*

296 *al.*, 1999). In our analysis, we used four treatments, with the different volume of soft rock to sand ratios of

297 0:1 (CK), 1:5 (C1), 1:2 (C2), and 1:1 (C3), respectively. During the whole incubation period, the CK and

298 C3 treatment demonstrated the same mineralization reaction characteristics, reaching a peak on the 3rd day,

299 followed first by a rapid and subsequently a slow decline (Fig. 3). This can be explained in that the soil

300 microenvironment was still at the beginning of the reaction and that   the compound soil organic carbon in

301 the initial stage of mineralization was mostly in the form of complex compounds. Thus, during this stage

302 only a few small molecular compounds were easily decomposed. Microorganism need to simplify the

303 complex compound before it can be absorbed and utilized, which is indicated by a rapid rising phase of the

304 respiratory rate at the initial stage (Li, 2000; Alvarez *et al.*, 1998). The reaction characteristics of the C1

305 and C2 treatment were similar as the trend of decrease was observed throughout the complete incubation

306 period. All the treatments can be divided into two stages: a rapid decline on days 1 to 11 and a steady

307 decline on days 11 to 30. The cumulative mineralization on day 11 reached 55%-74% of the total

308 mineralization (Fig. 4), which was consistent with the study of Zhang *et al.* (2011). During the early

309 mineralization stage, the organic matter mainly decomposed by soil microbes is derived from animal and

310 plant residues and their secretions (Li *et al.*, 2010). Thus, many active organic substances such as sugars

311 and proteins were easily decomposed in the soil at this initial stage providing abundant carbon sources and

312 nutrients for soil microorganisms and promoting microbial activity. With the prolongation of cultivation

313 time, the active organic components, which were easily to decompose within the soil, were gradually used

314   up by the microorganisms and the remaining components such as lignin and cellulose are more difficult to

315   be access by the microorganisms (Kögel-Knabner *et al*., 2010; Yang *et al*., 2007). Therefore, the

316   mineralization rate showed a trend from fast to slow which mirrors the decomposition rate, whereas the

317   cumulative mineralization showed a cumulative trend of a gradual decrease in release intensity

318   (Franzluebbers *et al.*, 2001; Li *et al.*, 2018b). Obviously, the amount of soil nutrient plays an important role

319   in the organic carbon mineralization process. Kemmitt *et al.* (2008) studied the mineralization process of

320   some microorganisms and found that after fumigation with chloroform, which reduced the number of

321   microorganisms by 90%, the mineralization rate of organic carbon among all treatments had no significant

322   difference compared to the control treatment. Thus, the mineralization of soil organic matter was limited

323   by a non-biological process that converts the substrate into microbial utilization (Kemmitt *et al.,* 2008). At

324   this stage, microorganisms only play a minor role as the available organic materials become a limiting

325   factor. Based on a hypothesis, Kemmitt *et al.* (2008) divided the process of humified soil organic matter

326   mineralization into two steps. The first step is a-biological and independent of any microbial processes. The

327   possible mechanisms include chemical oxidation or hydrolysis, diffusion from inaccessible soil pores or

328   aggregates, desorption from the solid phase, and the action of extracellular stabilized enzymes. The second

329   step is the mineralization by the soil microorganisms of this small, now biologically available, trickle of

330   substrate derived from humified soil organic matter. This trickle of substrate is equally available to both

331   the small developing recolonizing population in the fumigated soil and the larger population in the non-

332   fumigated soil. Hypothetically, if the soil microorganisms acted directly on solid soil,   this would likely

333   cause a localized depletion over long periods as most soil microorganisms are immobile. Coming back to

334   the two-step hypothesis, the results of the first step are to convert the compounds into organic matter for

335   microbial use, and the second step is to transfer these substances via diffusion to other microbes. Kemmitt

336   *et al.* (2008) described the non-biological dominated mineralization process as similar to that of

337   microorganisms acting directly on solid soil. Sollins *et al.* (1996) also believe that the mineralization

338   process and unstable processes of soil organic matter cannot be enhanced by increasing the activity of

339   microorganisms. The mineralization process in their study may be a comparable process as that described

340   by Kemmitt *et al.* (2008) for the end of the first stage and the beginning of the second stage. Taken together,

341   a special research is needed about the role of microorganisms during the mineralization process.

342   Despite the same, comparable incubation conditions within our experiments, there were significant

343   differences in soil organic carbon accumulation mineralization (C_t) with different compounding ratios,

344   which was C3>C1>C2>CK. This indicates a consistent trend with the content of organic carbon (Fig. 2).

345   The low content of soil organic carbon in the CK treatment affects the mineralization rate of soil organic

346   carbon, which results in a relatively small cumulative release of CO_2. The aeolian sandy soil has a higher

347   sand content, larger permeability coefficient, and a serious water and fertilizer leakage. On the other hand,

348   there are many small particles in the soft rock, which are hydrophilic and adsorbent. In our experiment,

349   mixing soft rock and aeolian sandy soil in a certain proportion promoted the increase of organic carbon

350   content and mineralized amount. The results of this study indicated that the soil clay and silt content

351   increased with adding more soft rock. When the content of soft rock was 17% (C1 treatment), the soil

352   texture was then a sandy loam (Fig. 7), and the cumulative mineralization rate of soil organic carbon was

353   the lowest at the beginning (Fig. 5). When the content of soft rock was 33% (C2 treatment), the soil texture

354   was loam, and the soil organic carbon accumulation mineralization rate was similar to the C1 treatment,

355   indicating that a compound ratio of soft rock and sand between 1:5 to 1: 2 can promote the accumulation

356   of soil organic carbon.

357   From the scanning electron microscope image (Fig. 6-a) it can be seen that the soil particles in the CK

358   treatment (aeolian sandy soil) do not adhere to each other, the spacing between the soil particles was large,

359   and the pores developed, mainly non-capillary pores. Therefore, the aeolian sandy soil has a good

360   ventilation effect but it has difficulties in effectively maintaining the moisture, so it will leak water and

361   fertilizer, which was not conducive for plant growth. The soil composition of CK treatment was single and

362   the texture uniform, most of which were sand grains. After the addition of soft rock in different proportions,

363   the soil texture changed from sand to sandy loam to loam to silt loam (Fig. 7). Fig. 6-b shows that some of

364   the single particles have a higher degree of roundness, and some soil particles with rough surface and mutual

365   adhesion have agglomerate characteristics, which mainly derive from the soft rock. Compound soil began

366   to appear on the surface of the clay, which was conducive to the benign transformation of the compound

367   soil structure (Fig. 6-b, c, d). The reasons for the formation of the structure can be summarized in three

368   types: (1) When the soft rock was mixed with sand, the silt and clay particles in the soft rock came in contact

369   with the aeolian sand, whereas the silt and clay particles were gradually adsorbed around the sand; (2) In

370   the process of artificial improvement, irrigation and organic matter increased the cementing material in the

371   compound soil, and the cementation promoted the formation of soil aggregates; (3) Various external stresses

372   such as crop root activity and animal activities promote the formation of soil aggregate structure. It can be

373   concluded that the addition of soft rock was improving the loose structure of the sandy land, promoting the

374   agglomeration and cementation of soil, and thus improving the aeration and permeability of soil. However,

375   adding more soft rock does not consequently lead to better results. When the soft rock content reached 50%

376   (C3 treatment), the large particles were not enough to support the soil structure, entailing the collapse of

377   the soil (Fig. 6-d). At this composition, the soil texture was a silt loam, and the cumulative mineralization

378   rate was the highest of all treatments. Thus, the change of soil structure plays an important role in organic

379   carbon mineralization. The change in mechanical properties of the soil caused by the change of soil structure

380   remains to be further studied.

381   In addition to soil structure, texture, and nutrients, soil organic carbon mineralization also has an

382   impact on water content. In our study, the organic carbon retention effect in the C2 treatment was the best.

383   The high moisture content may have little effect on the amplitude variation, similar to the variation law

384   revealed by Jia *et al*. (2017), who believed that the cumulative mineralization amount and mineralization

385   rate of organic carbon increase with the increase of soil moisture content but then subsequently gradually

386   decreases. In our previously reported experiments (Sun and Han, 2018), we showed that the C2-like treated

387   compound soil had the highest water content and the C1-like treatment had the greatest impact on soil water

388   storage. According to Cooper *et al.* (2011), temperature was the primary factor driving soil organic carbon

389   mineralization. The mineralization rate and cumulative mineralization amount of soil organic carbon

390   increased with the increase of cultivation temperature, though the most significant effect of the temperature

391   observed was outside the normal temperature range. Among the different agricultural measures, tillage

392   systems also change the stability of soil aggregates, thereby affecting the loss of carbon stocks. Stable

393   macroaggregates in cultivated soil can retain more carbon than microaggregates but macroaggregates were

394   more easily mineralized than microaggregates (Goh, 2004). The soil also contains many different metal

395   ions. One study indicated a significant negative relationships between Fe-oxyhydroxides, Al-

396   oxyhydroxides and Al-humus complex content, and soil C mineralization, suggesting a mineral control of

397   C mineralization (Rasmussen *et al.*, 2006). Therefore, the adsorption of these soil minerals can prevent the

398   microorganic decomposition of organic matter. Taken together, soil nutrients, texture, water content,

399   temperature, tillage measures, metal ions, and many other factors cause differences in the soil organic

400   carbon mineralization. Future research should therefore focus on the later stages of the factors not involved.

401   Soil potentially mineralizable organic carbon (C_0), also known as biodegradable carbon, is the total

402   amount of organic matter that can be decomposed under the action of microorganisms (Guo *et al.*, 2019).

403   The C_0 values in this study were consistent with the changes in C_t value, and the specific performance was

404   C3>C1>C2>CK. The reason was that with the increase in soft rock content, the non-capillary space between

405   the sand grains was filled by the soft rock, increasing the capillary pressure and promoting the formation

406   of the soil aggregate structure. The soft rock was also rich in carbonate and other mineral components. As

407   the soft rock volume fraction increased, the cementation force of the compound soil also increased

408   significantly. Because the organic carbon content of the compound soil is significantly higher than that in

409   the CK treatment, the activity of plant roots and animals in the compound soil also promotes the fusion of

410   soft rock and sand (Han *et al.*, 2012). Li *et al.* (2010) studied the soil organic carbon mineralization in the

411   Loess Plateau. They found that that the organic carbon mineralization rate constant k was neither affected

412   by soil nutrient nor by pH, but it was influenced by particle composition. The results in our study showed

413   that there was no significant difference in the k-value between the C1, C2, and C3 treatments, though they

414   were significantly lower than in the CK treatment. Also, the changes in $T_{1/2}$ and k values were opposite.

415   One explanation might be that the long-term application of chemical fertilizers in this experiment increased

416   the inorganic nitrogen content, such as soil nitrate nitrogen and ammonium nitrogen, which then reacts with

417   other compounds such as lignin or phenol present in the soil. This reaction lowers the decomposition

418   properties changed of organic carbon had (Jenkinson *et al.*, 1985; Liu *et al.*, 2017). Other studies showed

419   that the increased amount of soft rock can promote the formation of aggregates in the compound soil, so

420   that some organic carbon particles are encapsulated by the aggregates thus avoiding degradation and

421   increasing the retention time of organic carbon in the soil (Pulleman and Marinissen, 2004; Chevallier *et*

422   *al.*, 2004). The C_0/SOC value can reflect the solid storage capacity of the compound soil organic carbon:

423   the larger the ratio, the stronger the soil organic carbon mineralization ability, and vice versa. The results

424   of this study indicated that the C_0/SOC values in all treatments were C3>CK>C2>C1, with no significant

425   difference between C1 and C2, which was consistent with the trend observed in the soil organic carbon

426   accumulation mineralization rate.

427

428   **CONCLUSIONS**

429   The soil organic carbon content can be significantly increased by the different compound ratios of soft rock

430   and sand. With an increased soft rock content, the content of soil sand gradually decreased, while the content

431   of clay and silt gradually increased, with the largest increase in silt. The soil texture changed from sand to

432   sandy loam, then to loam and silty loam. The results of the scanning electron microscopy showed that the

433   specific surface area between large particles and small particles increased with the increase of volume

434   fraction between soft rock and sand. Interestingly, when the soft rock volume fraction was 50%, the soil

435   structure collapsed. The C1 and C2 treatments had the highest mineralization rate on the first day of

436   incubation, whereas the CK and C3 treatment reached their maximum on the third day of cultivation. The

437   whole cultivation process can be divided into a rapid decline between days 1 to 11 and a slow decline

438   between days 11 to 30. With the prolongation of cultivation time, the accumulation intensity of cumulative

439   mineralization of soil organic carbon was gradually reduced. The cumulative mineralization rate in the C1

440 and C2 treatments was the lowest in all treatments, and C_0/SOC was consistent with its variation rule. The

441 organic carbon turnover rate was significantly decreased and the retention time in soil was increased with

442 the addition of soft rock. Here, the C1 and C2 treatment showed the best effect. The accumulation of

443 compound soil organic carbon can be significantly increased when the ratio of soft rock to sand was 1:5 to

444 1:1. A comprehensive mineralization index and scanning electron microscopy analysis indicated that the

445 compounding ratio of 1:5 to 1:2 can be used as an important basis for farmland carbon sequestration and

446 soil remediation measures.

447

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451

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

1 **Table 1 Regression equation of soil organic carbon mineralization rate and cumulative**

2 **mineralization under different compounding ratios.**

Index	Treatment	Regression equation	r
Mineralization rate	CK	$y_1 = -12.10 \ln(x) + 41.28$	0.7933**
	C1	$y_1 = -14.56 \ln(x) + 54.378$	0.9298**
	C2	$y_1 = -10.06 \ln(x) + 40.408$	0.9595**
	C3	$y_1 = -14.40 \ln(x) + 64.713$	0.8679**
Cumulative mineralization	CK	$y_2 = 71.928 \ln(x) + 30.107$	0.9935**
	C1	$y_2 = 132.40 \ln(x) + 9.2284$	0.9752**
	C2	$y_2 = 121.50 \ln(x) - 14.676$	0.9757**
	C3	$y_2 = 234.98 \ln(x) - 60.922$	0.9795**

3   Notes: CK: the volume ratio of soft rock to sand is 0:1; C1: the volume ratio of soft rock to sand is 1:5;

4   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_1: CO_2

5   production rate, mg kg^{-1} d^{-1}; y_2: CO_2 accumulative release amount, mg kg^{-1}; x: incubation day, d; ** means

6   significant correlation at 0.01 level.

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

1   **Table 2 Cumulative mineralization of SOC after the 30 days of incubation and parameters of its**

2   **kinetic equations.**

Treatment	C_t (mg kg^{-1})	C_0 (mg kg^{-1})	k (d^{-1})	$T_{1/2}$	C_0/SOC (%)	R^2
CK	274.44 c	257.44 c	0.1671 a	4.15 b	12.78 b	0.9748**
C1	517.03 b	526.05 b	0.0824 b	8.41 a	12.42 b	0.9643**
C2	437.22 b	484.61 b	0.0697 b	9.94 a	13.61 b	0.9947**
C3	803.88 a	936.95 a	0.0622 b	11.14 a	21.25 a	0.9983**

3   Notes: CK: the volume ratio of soft rock to sand is 0:1; C1: the volume ratio of soft rock to sand is 1:5;

4   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

5   amount of organic carbon cumulative mineralization, C_0 for amount of potential mineralizable organic

6   carbon, k for constant of organic carbon mineralization rate, $T_{1/2}$ for half turnover period, C_0/SOC for

7   ratio of potential mineralizable organic carbon to total organic carbon in compound soil. Values followed

8   by different letters in the same column mean significant difference at 0.05 level between treatments, **

9   indicates a extremely significant level of 1%.

Figure 1

Test plot layout for soft rock and sand compound soils.
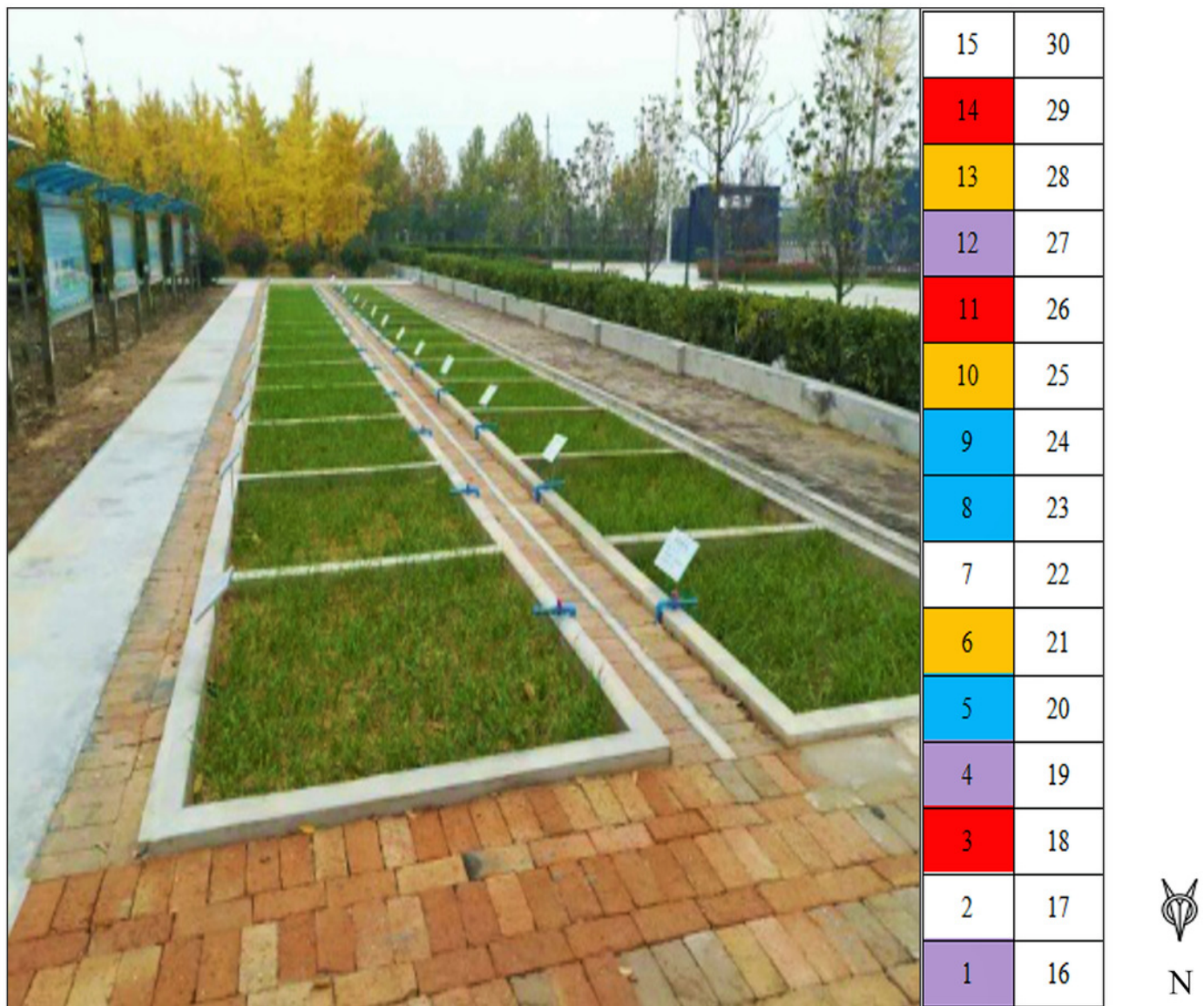
Figure 2

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.
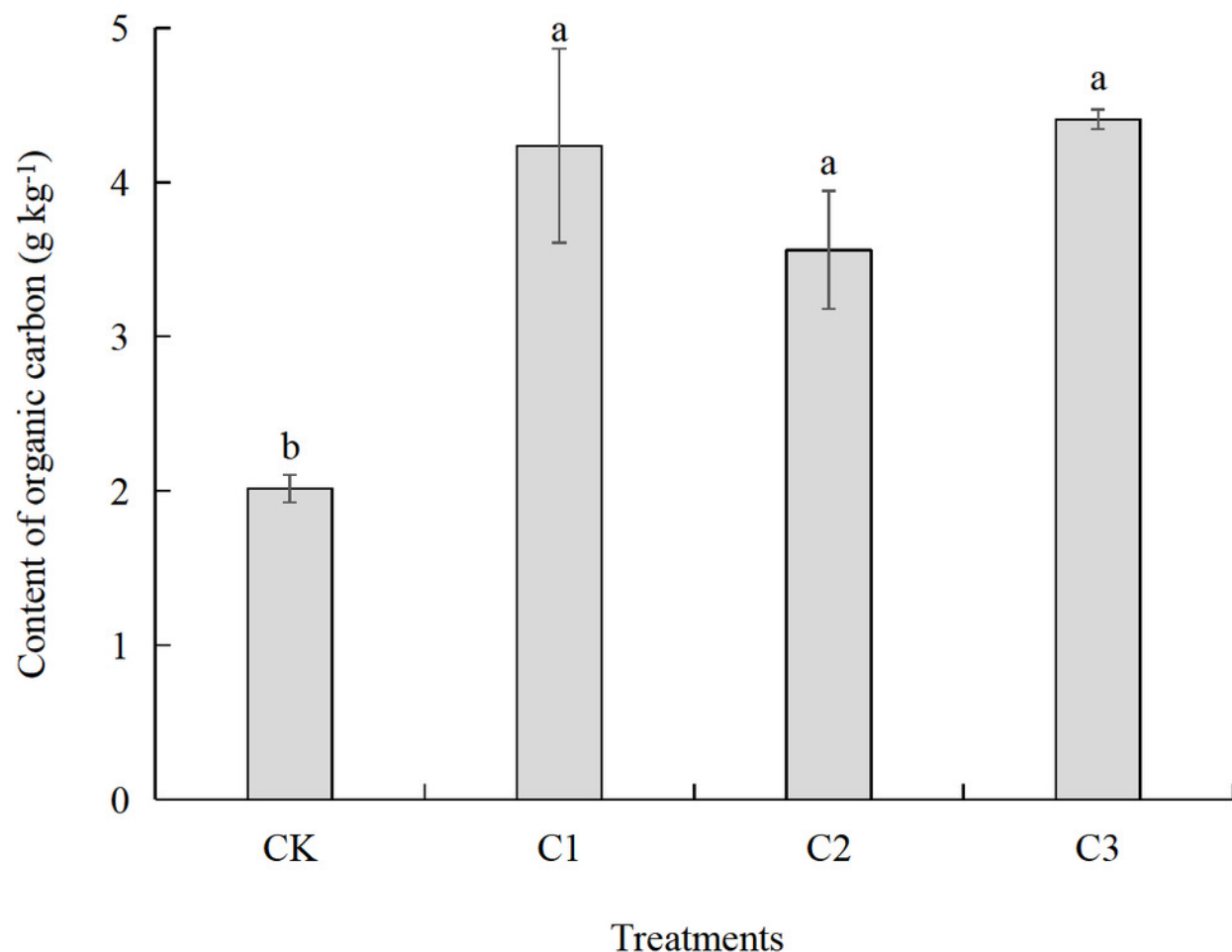
Figure 3

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.
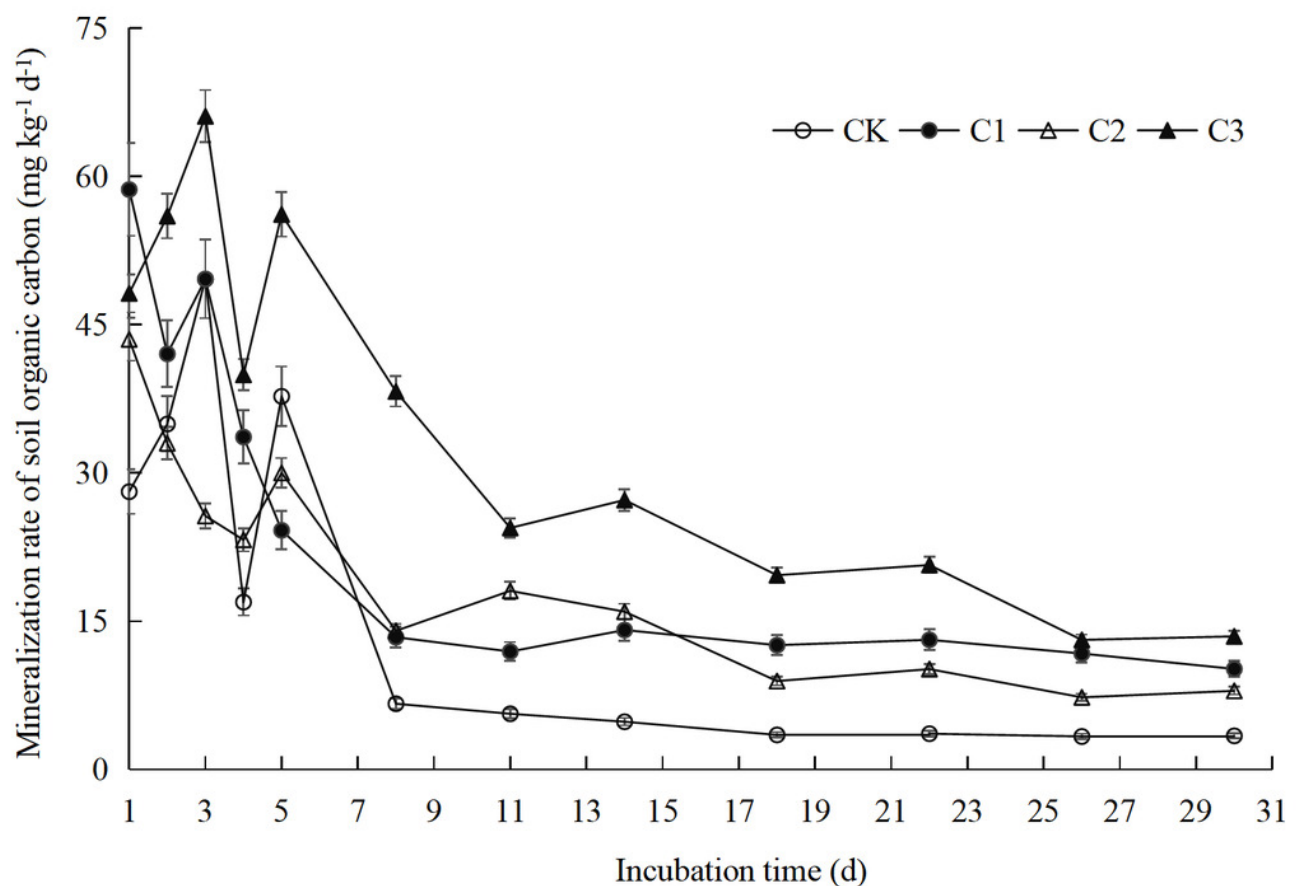
Figure 4

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.
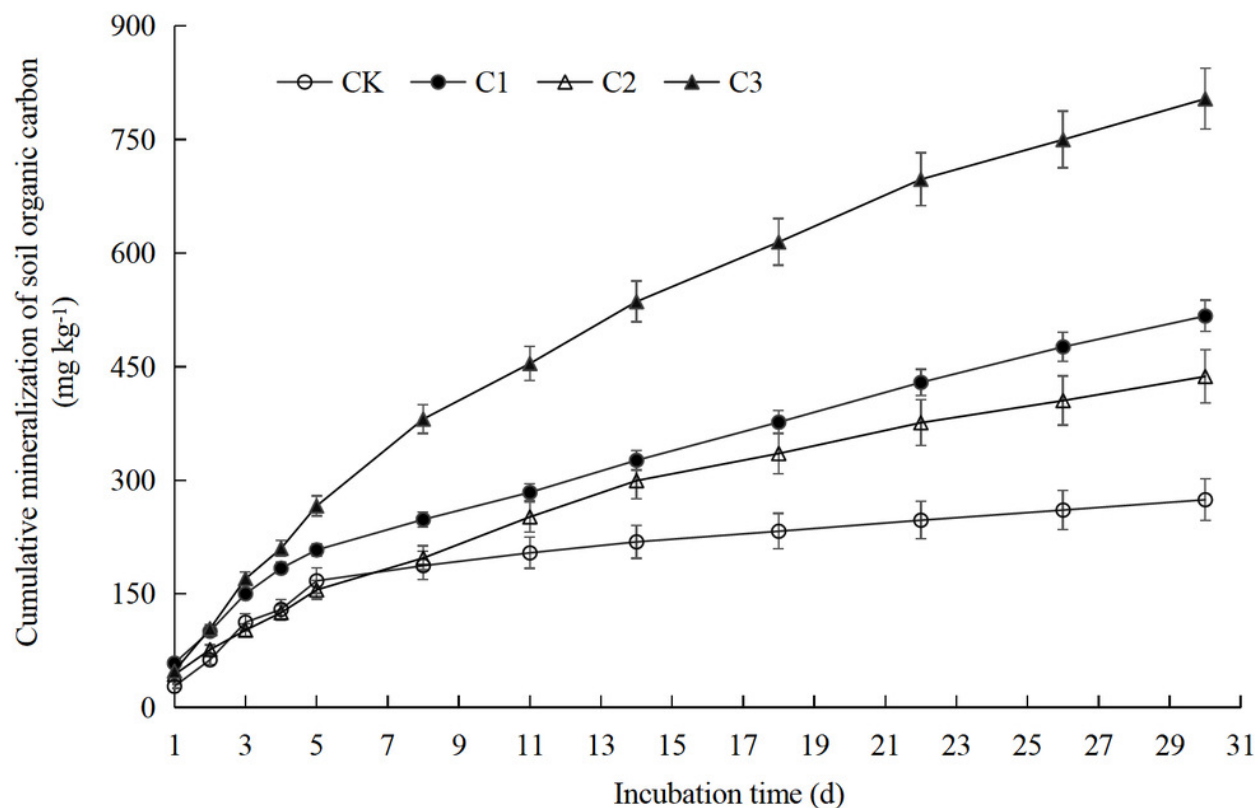
Figure 5

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.
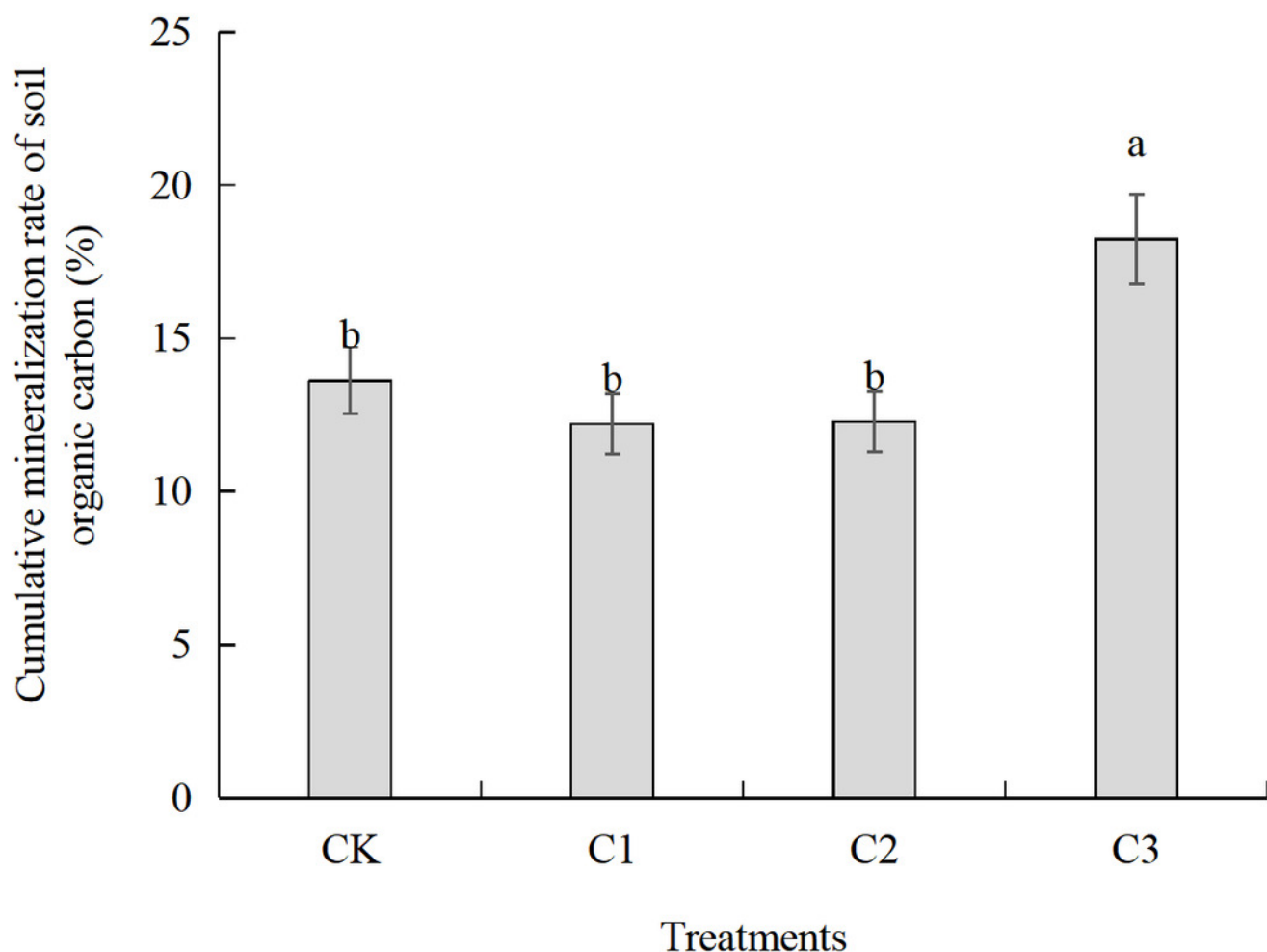
Figure 6

The microstructure of compound soil in different proportions of soft rock and sand.

(a): the volume ratio of soft rock to sand is 0:1 (CK); (b): the volume ratio of soft rock to sand is 1:5 (C1); (c): the volume ratio of soft rock to sand is 1:2 (C2); (d): the volume ratio of soft rock to sand is 1:1 (C3). The magnification is 1000 times.
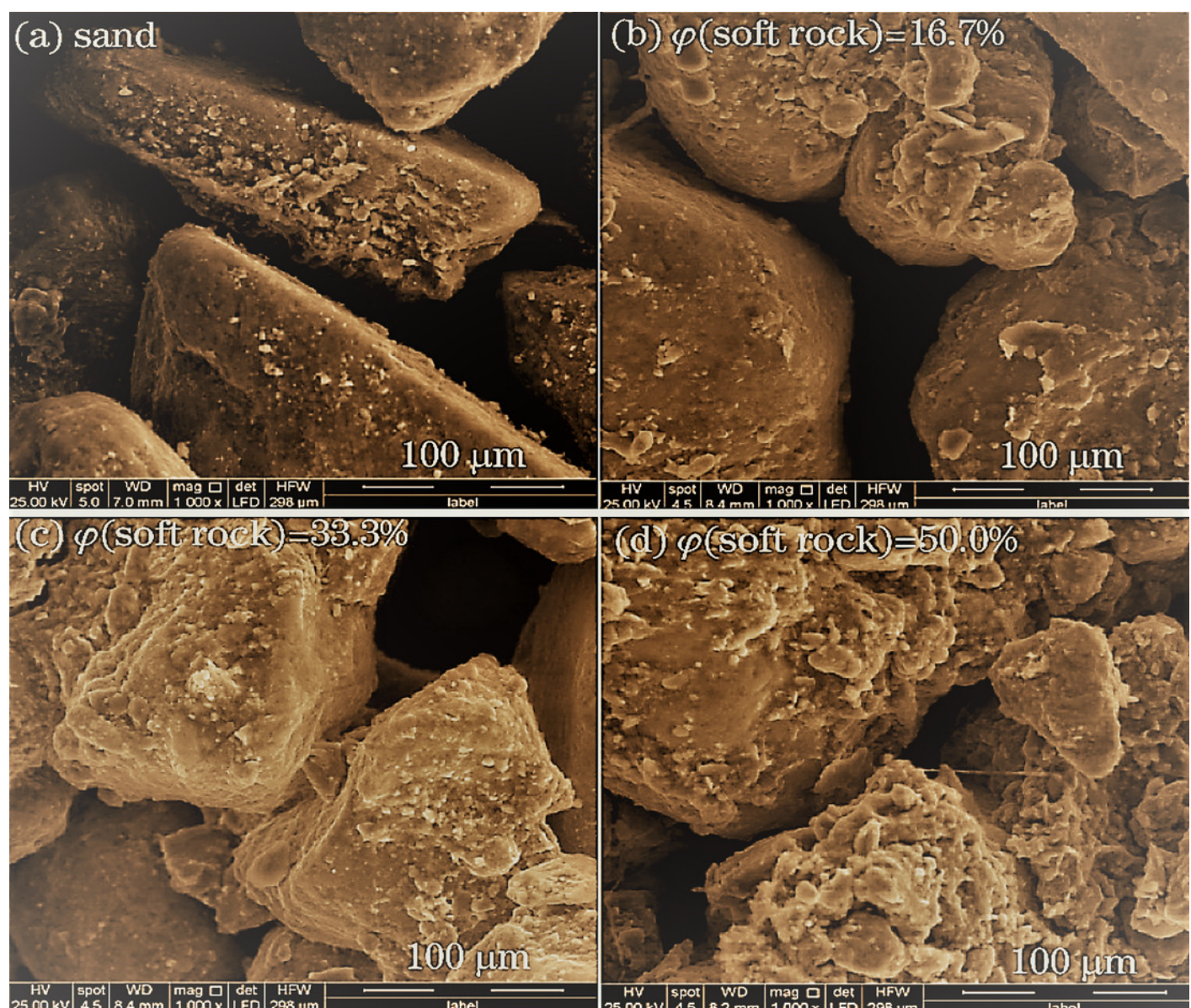
Figure 7

The soil particle composition under different compound ratios 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. Lowercase letters indicate significant differences (at 0.05 level) in the same particle composition between treatments.