Hindawi
Mathematical Problems in Engineering
Volume 2020, Article ID 5463107, 7 pages
https://doi.org/10.1155/2020/5463107

Research Article

Response of Fractal Analysis to Soil Quality Succession in Long-Term Compound Soil Improvement of Mu Us Sandy Land, China

Haiou Zhang,[1,2] Jiancang Xie,[1] Jichang Han,[2] Haipeng Nan,[1] and Zhen Guo[2]

[1]*State Key Laboratory of Eco-Hydraulics, Northwest Arid Region of China, Xi'an University of Technology, Xi'an 710048, Shaanxi Province, China*
[2]*Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an 710075, Shaanxi Province, China*

Correspondence should be addressed to Jiancang Xie; jcxie@xaut.edu.cn

Received 31 October 2019; Revised 15 January 2020; Accepted 28 January 2020; Published 18 February 2020

Academic Editor: Jian G. Zhou

The degraded aeolian sandy soil in China's Mu Us Sandy Land requires amendment before it can be suitable for maize or other agricultural production. The addition of material from the local "soft" bedrock can create a new compound soil whose particle composition and structural stability are key issues for sustainable soil development in the region. We used field data from 2010 to 2018 to study the variations in fractal characteristics of compound soil particles at soft rock to sand volume ratios of 1 : 1, 1 : 2, and 1 : 5, along with changes in soil organic matter. Over the study period, all three compound soils showed gradual increases in clay and silt content with corresponding decreasing sand content. The fractal dimension (FD) of particles at ratio 1 : 2 increased by 8.8%, higher than those at 1 : 1 (8.6%) and 1 : 5 (7.7%). The organic matter content (OMC) of particles at ratio 1 : 2 reached a maximum (6.24 ± 0.30 g/kg), an increase of 12 times over the original value. The FD and OMC of particles at ratios 1 : 1 and 1 : 5 were less stable but showed overall increase. The 1 : 2 ratio compound soil was most suitable for maize growth as its clear increase in silt and clay content most improved the texture and OMC of the original sandy soil. Such research has important theoretical and practical significance for understanding the evolutionary mechanism and sustainable use of the compound soil in agriculture within the Mu Us Sandy Land.

1. Introduction

Soil particle composition is an important indicator used for monitoring and evaluating desertification in northern China as it has a vital impact on the biological, physical, and chemical properties of the soil [1, 2], which directly affect the abundance and deficiency of soil nutrients, as well as changes in organic matter content [3]. Soil is a porous medium composed of multisized particles with irregular structure, with certain fractal characteristics. Several studies have shown that the soil mass (volume) FD is an intrinsic property of soil [4–6] and represents a comprehensive index of soil particle composition. Fractal theory has been applied to soil science to investigate and quantify complex problems associated with soil state and processes [1]. Ai et al. [7] used a fractal method to characterize soil particle size distribution and determined the fractal characteristics of synthetic soil for cut-slope revegetation in the purple soil area of China. Liao et al. [8] and de Bartolo et al. [9] applied fractal analysis to detect the spatiotemporal variability of soil moisture content for different land use activities.

This study focused on the Mu Us Sandy Land, a 3.98×10^6 ha [10] region severely affected by wind erosion and desertification; this is one of the four major sand areas in China that requires ecological restoration. The region comprises 1.67×10^6 ha [11] of easily eroded bedrock ("soft rock" hereafter) that provides the main source of the coarse sand entering the Yellow River. On the contrary, the region has extensive solar resources, relatively abundant precipitation, and a shallow groundwater table, as well as other environmental conditions suitable for the development of high-value agriculture. Aeolian sandy soil has almost no structure, and although it has great water permeability under dry and wet conditions, its water-retention performance is poor. Soft rock contains a large amount of montmorillonite, which expands rapidly when it encounters water, and hence, it has good water-holding properties. Therefore, it can be used as a natural water-retaining agent [10]. Several scholars have ascertained that the properties of soft rock and sand soil are complementary to each other; soft rock can be used as a natural material for rehabilitating sandy land into cultivated land. Based on the analysis of the physical and chemical properties of the mixed soil, with different proportions in laboratory test and the practical difficulty in construction, it is concluded that the suitable mixing ratio of soft rock and sand volume is 1 : 5–1 : 1 for crop growth, with the characteristic water retention and air permeability [12, 13].

The new compound soil with soft rock and aeolian sand soil is heterogeneous in nature; the physical and chemical properties still require some time for stabilization. Furthermore, change in the agricultural planting structure will affect soil development, changing the physical, chemical, and biological properties of the soil [14]. Therefore, the particle composition and OMC of the new compound soil are the primary concerns of sustainable agricultural management. Although abundant research has assessed the nutrient characteristics and crop yields in such compound soils [13, 15–17], no research has considered their particle distribution characteristics or the succession of different proportions over time. In this study, we analyzed compound soil from the Mu Us Sandy Land with soft rock to sand volume ratios of 1 : 1, 1 : 2, and 1 : 5, from 2010 to 2018, and calculated the FD of compound soil particles using the method proposed by Wang et al. [18]. The results allowed us to analyze the driving mechanisms of soil stability and the dynamic change characteristics of organic matter, providing a theoretical basis for the sustainable utilization of the new soil in Mu Us Sandy Land.

2. Materials and Methods

2.1. Research Area. We conducted this study using a long-term scientific observation test station and test plot at the sand remediation demonstration project in Da Jihan Village, Xiao Jihan Township, Yu Yang District, Yu Lin City (109°28′58″ to 109°30′10″E, 38°27′5″ to 38°28′23″N). The geographic, climatic, and hydrological conditions are representative of the Mu Us Sandy Land, with a typical midtemperate semiarid continental monsoon climate. The spatiotemporal distribution of precipitation in this region is uneven, with July to September (especially August) accounting for 60–75% of the annual precipitation (250–440 mm). The interannual variability of precipitation is large (wet years are 2–4 times wetter than the dry years).

In combination with the region's ample sunlight, these characteristics can produce high yields of maize and potatoes in acceptable soils. The study site was mainly composed of aeolian sandy soil whose loose structure results in poor water-holding capacity and high evapotranspiration, leading to frequent water shortages. Sampling showed that these soils were low in nutrients, with total nitrogen of 0.75 g/kg of soil mass, total phosphorus of 0.63 g/kg, total potassium of 26.51 g/kg, and organic matter of 0.30 g/kg. The local soft, easily weathered bedrock is poorly cemented with low structural strength and poor permeability but good water-retention capacity, such that local groundwater provides moisture for plant growth. Tests of the local soft rock showed an OMC of 6.2 g/kg, total nitrogen of 0.125 g/kg, total phosphorus of 0.379 g/kg, a bulk density of 1.25 g/cm^3, and capillary porosity of 52.7%. This rock material was mixed with the sandy material to form the compound soils for our tests.

2.2. Experimental Plot Design. In 2010, a soft rock and sand complex remediation demonstration project established nine 12 m × 5 m long-term test plots. The top 30 cm of the original sandy soil was altered to soft rock to sand volume ratios of 1 : 1, 1 : 2, or 1 : 5 in nine separate plots (three replicates for each ratio). The annual planting season for spring corn, the main cash crop in the area, is in mid-May, and harvesting is carried out, once a year, in late September, approximately 130 days after sowing. The corn varieties planted were Yudan 9 in 2010–2014 and Xianyu 335 in 2015–2018, with seeding depth of approximately 5 cm, row spacing of 60 cm, and planting density of 65,000 plants ha^{-1}. All plots received the same irrigation and fertilization. Compound fertilizer (90 kg N ha^{-1}, 40 kg P ha^{-1}, and 75 kg K ha^{-1}) was applied in 20 cm deep furrows and covered with soil using a fertilizer applicator when seeding. Urea was applied at 187 kg N ha^{-1} at the corn jointing stage as part of the local applied levels of fertilizer management. During the period of maize growth, water was irrigated approximately five times, with approximately 55.6 mm water each time. In this experiment, after corn harvesting, soil samples of 0–30 cm undergoing each treatment were collected from a total of 15 sample points in the upper, middle, and lower parts of each plot and mixed evenly using the "S"-shaped sampling method. The samples were then analyzed to determine the compound soil's physical and nutrient contents.

2.3. Experimental Method. The collected soil samples were naturally dried after removing grass, roots, and other debris, and then ground and passed through a 2 mm sieve. The soil particle composition was determined using a laser particle size analyzer Mastersizer 2000 (Malvern Panalytical, Malvern, UK). After obtaining the average value for each plot, the soil texture types were determined using the soil texture automatic classification system (STAC) [19]. The particle size classification was based on the American classification standard (USDA) in 1951. The OMC was determined using the potassium dichromate external heating method [3].

2.4. Particle FD Calculation. We used the calculation method proposed by Wang et al. [18]. The formulas are as follows:

$$\left(\frac{\overline{d}_i}{\overline{d}_{\max}}\right)^{3-D} = \frac{V_{\left(\delta<\overline{d}_i\right)}}{V_{(T)}},$$
$$\lg\left\{\frac{V_{\left(\delta<\overline{d}_i\right)}}{V_{(T)}}\right\} = (3-D)\lg\left(\frac{\overline{d}_i}{\overline{d}_{\max}}\right), \tag{1}$$

where $\overline{d}_i$ is the average diameter of a certain particle size, $V_{\left(\delta<\overline{d}_i\right)}$ is the volume of the particle with a particle size smaller than $\overline{d}_i$, $V_{(T)}$ is the total volume of the particle, and $\overline{d}_{\max}$ is the maximum particle size. Linear regression analysis was performed with $\lg\left\{V_{\left(\delta<\overline{d}_i\right)}/V_{(T)}\right\}$ and $\lg(\overline{d}_i/\overline{d}_{\max})$ as vertical and horizontal coordinates, respectively, and $(3-D)$ is the slope of the straight line.

3. Results

3.1. Annual Variations in Compound Soil Particle Composition. The compound soil composition clearly changed from 2010 to 2016 (Table 1). Over time, the clay content of the compound soil with ratio 1 : 2 increased steadily, reaching 2.68 times its initial value (highest of any test), while that of the 1 : 1 and 1 : 5 compound soils were more variable but showed an overall increase of 2.38 and 2.45 times the initial value, respectively. The silt content of the 1 : 1, 1 : 2, and 1 : 5 ratio compound soils increased by 2.4 times, 1.52 times, and 1.64 times, respectively, while the sand content decreased by 51.4%, 16.1%, and 24.4%, respectively. Overall, the three compound soils progressed from loamy sand to sandy loam to silt loam, with finer and improved texture.

3.2. Fractal Characteristics of Compound Soil Particles by Year. The FD calculations implied soil textures ranging from coarse to fine, with FD from low to high (Table 1). Over time, the FD of the soil particles increased gradually, achieving a significant difference from the starting condition ($P < 0.05$). The FD values of the 1 : 2 ratio compound soil particles increased by 8.8% with a significant difference between 2010 and 2013 ($P < 0.05$), becoming stable after 2014 ($P < 0.05$). The FD of the 1 : 1 ratio compound soil increased, decreased, and then increased, with an overall increase of 8.6%. The initial increase rate of FD of the 1 : 5 ratio compound soil was rapid and showed no significant difference ($P > 0.05$) after 2012; the FD increased overall by 7.7%. The 1 : 2 ratio compound soil clearly showed the greatest improvement; the introduction of more fine particles into the soil improved its internal structure and created a higher soil volume FD, indicating the benefits of mixing soft rock into sandy land soils.

3.3. Relationship between FD and Soil Composition. As the FD of soil particles is related to the distribution of the soil particle size, we analyzed the linear correlation between the FD of the 1 : 1, 1 : 2, and 1 : 5 ratio compound soil particles and the overall sand, silt, and clay contents (Table 2). The FD of the three compound soils and sand (0.05–2 mm) showed a very significant negative correlation that was highest for the ratio 1 : 2, followed by that for ratios 1 : 1 and 1 : 5. There was a significant positive correlation with silt (0.002–0.05 mm) that was highest for the ratio 1 : 2, followed by that for ratios 1 : 1 and 1 : 5; this was also true for clay (<0.002 mm), which was highest for the ratio 1 : 5, followed by those for ratios 1 : 1 and 1 : 2. These results confirm that higher soil clay and silt content led to higher FD, finer texture, and tighter soil in contrast to sand. Therefore, silt and clay are important driving factors for the development of improved texture in the compound soil.

3.4. Relationship between FD and Organic Matter. Soil particles provide physical protection for organic carbon. The OMC of the 1 : 1, 1 : 2, and 1 : 5 ratio compound soils showed an overall upward trend over time, with a clear significant difference ($P < 0.01$) from 2010 to 2018. In addition, the soil OMC between the three compounds generally showed significant differences ($P < 0.05$). The 1 : 1 compound soil reached its highest OMC (5.17 ± 0.17 g/kg) after 8 years (2017); after 9 years, this value increased by 10 times. The 1 : 2 ratio compound soil showed a continuous increase in organic matter over time; after 9 years (2018), the OMC reached its highest value (6.24 ± 0.30 g/kg), 12 times higher than before planting. The 1 : 5 ratio compound soil reached its highest OMC (5.28 ± 0.15 g/kg) after 4 years (2013) and then decreased before becoming stable. After 9 years, this value increased by 11 times, as shown in Figure 1.

The FD of soil particles and OMC were significantly positively correlated for all three compounds (Figure 2). The 1 : 2 ratio compound soil showed the greatest positive correlation with organic matter ($R = 0.936$, $P < 0.01$), followed by the 1 : 5 ($R = 0.625$, $P < 0.01$) and 1 : 1 ($R = 0.555$, $P < 0.01$) ratio soils. There was also a significant positive correlation in the relationship between FD and organic matter content. These results show that higher silt and clay content is vital for the accumulation of organic matter in compound soils within the study area's desertified land.

4. Discussion

The fractal dimension of particles is a comprehensive index of soil particle composition. Fractal theory is applied to soil science to investigate complex problems such as soil state and processes and quantify these variables to some extent [1]. Some researchers [20, 21] calculated the fractal dimension of the particle size distribution by using the soil particle mass distribution to characterize soil particle size and the uniformity of the texture composition. In this study, the FD of soil particle volume was used to characterize the size of soil particle diameter and the uniformity of texture composition, so as to characterize the quality and development of the newly created soil-soft rock and sand compound soil. The FD of soil volume, an intrinsic property of soil, is the same as the FD of soil mass. However, calculating

Table 1: Particle composition of the compound soil samples with volume mixing ratios of 1 : 1, 1 : 2, and 1 : 5 in the 0–30 cm layer of the experimental field from before planting and 2010–2016.

Soft rock : sand	Particle composition	Before planting	2010	2011	2012	2013	2014	2015	2016
1 : 1	Sand% (0.05–2 mm)	82.59 ± 0.33	76.30 ± 0.60	68.46 ± 0.60	69.20 ± 0.52	67.34 ± 1.05	63.49 ± 0.81	42.83 ± 0.29	40.73 ± 1.04
	Silty% (0.002–0.05 mm)	14.57 ± 0.28	18.20 ± 0.66	24.02 ± 0.76	27.36 ± 0.73	29.02 ± 1.06	30.54 ± 0.87	50.67 ± 0.53	49.68 ± 0.73
	Clay% (<0.002 mm)	2.84 ± 0.12	5.51 ± 0.32	7.52 ± 0.38	3.44 ± 0.31	3.64 ± 0.27	5.96 ± 0.32	6.50 ± 0.29	9.59 ± 0.50
	Texture	Loamy sand	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Silt loam	Silt loam
	D	2.44 ± 0.01a	2.54 ± 0.01c	2.59 ± 0.01e	2.47 ± 0.01b	2.48 ± 0.01b	2.56 ± 0.01d	2.58 ± 0.01e	2.64 ± 0.01f
1 : 2	Sand% (0.05–2 mm)	85.40 ± 0.74	84.18 ± 0.92	82.78 ± 0.07	74.20 ± 0.76	72.51 ± 0.72	67.38 ± 0.82	63.88 ± 0.30	61.58 ± 0.15
	Silty% (0.002–0.05 mm)	12.53 ± 0.45	13.17 ± 0.94	13.58 ± 0.05	21.40 ± 0.36	23.03 ± 0.62	27.58 ± 0.93	30.45 ± 0.26	30.81 ± 0.13
	Clay% (<0.002 mm)	2.07 ± 0.29	2.65 ± 0.02	3.64 ± 0.05	4.40 ± 0.58	4.46 ± 0.17	5.04 ± 0.11	5.66 ± 0.14	7.61 ± 0.15
	Texture	Loamy sand	Loamy sand	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
	D	2.38 ± 0.02a	2.42 ± 0.00b	2.47 ± 0.00c	2.51 ± 0.02d	2.51 ± 0.01d	2.53 ± 0.00e	2.55 ± 0.00e	2.60 ± 0.00f
1 : 5	Sand% (0.05–2 mm)	88.37 ± 0.16	84.34 ± 0.44	82.70 ± 0.21	70.52 ± 0.59	77.18 ± 0.83	76.91 ± 0.47	68.70 ± 0.83	68.23 ± 0.49
	Silty% (0.002–0.05 mm)	10.37 ± 0.41	11.79 ± 0.57	14.48 ± 0.17	25.84 ± 0.57	19.30 ± 0.82	19.67 ± 0.47	27.74 ± 0.53	27.42 ± 0.59
	Clay% (<0.002 mm)	1.26 ± 0.29	3.87 ± 0.14	2.82 ± 0.04	3.64 ± 0.03	3.52 ± 0.05	3.42 ± 0.02	3.55 ± 0.35	4.35 ± 0.13
	Texture	Loamy sand	Loamy sand	Loamy sand	Sandy loam	Loamy sand	Loamy sand	Sandy loam	Sandy loam
	D	2.30 ± 0.03a	2.48 ± 0.00c	2.43 ± 0.00b	2.48 ± 0.00c	2.47 ± 0.00c	2.47 ± 0.00c	2.48 ± 0.01c	2.51 ± 0.01d

[1]Mean values in the table, and different letters within particle FD (D) rows mean significant difference (at 0.05 level) between different planting years in the compound soil of the same proportion in different years and with the same letters are not significantly different at $P < 0.05$ according to a protected LSD test.

Table 2: Relationships between the FD of compound soil particles in different proportions and the content of each grain fraction.

Soft rock : sand	D and sand (0.05–2 mm) X_1	D and silt (0.002–0.05 mm) X_2	D and clay (<0.002 mm) X_3
1 : 1	$D = -0.003X_{11} + 2.764$ $R^2 = 0.574$	$D = 0.003X_{21} + 2.431$ $R^2 = 0.458$	$D = 0.029X_{31} + 2.372$ $R^2 = 0.963$
1 : 2	$D = -0.007X_{12} + 3.019$ $R^2 = 0.894$	$D = 0.008X_{22} + 2.318$ $R^2 = 0.851$	$D = 0.038X_{32} + 2.326$ $R^2 = 0.952$
1 : 5	$D = -0.006X_{15} + 2.934$ $R^2 = 0.531$	$D = 0.006X_{25} + 2.333$ $R^2 = 0.438$	$D = 0.067X_{35} + 2.230$ $R^2 = 0.965$

[2]D: FD value; X_{1i}: sand content in different proportions of the compound soil; X_{2i}: silty content in different proportions of the compound soil; and X_{3i}: Clay content in different proportions of the compound soil.

the FD of soil volume requires fewer assumptions (for example, it need not assume that all soil particles have the same density regardless of size) and was therefore more reasonable for use in this study [18, 22]. In addition, with the development and application of laser diffraction technology, the size and number of soil particle volume distributions can be obtained relatively easily and accurately. More importantly, this study found that clay content was one of the key driving factors for soil texture improvement and organic matter enhancement of the sandy soil in the study area. However, relevant studies [18] determined that the percentage of soil clay volume and the FD of soil volume showed basically consistent change laws. Therefore, the FD of soil volume can be used to better characterize the change in clay content and the uniformity of texture composition of the new soil in Mu Us Sandy Land, China.

The significantly higher silt and clay content in the 1 : 2 ratio compound soil may be the result of interactions between the soft rock and sand mixture, progressive changes over multiple years, and the growth characteristics of maize. Crop growth effectively prevents the loss of fine particulate matter in sandy soils while promoting the deposition of fine particulate matter [13, 23]. The core challenge for agricultural productivity in this region is the loss of clay and mineral colloids from the soil. The initial composition of the soft rock has a significant effect on the particle composition

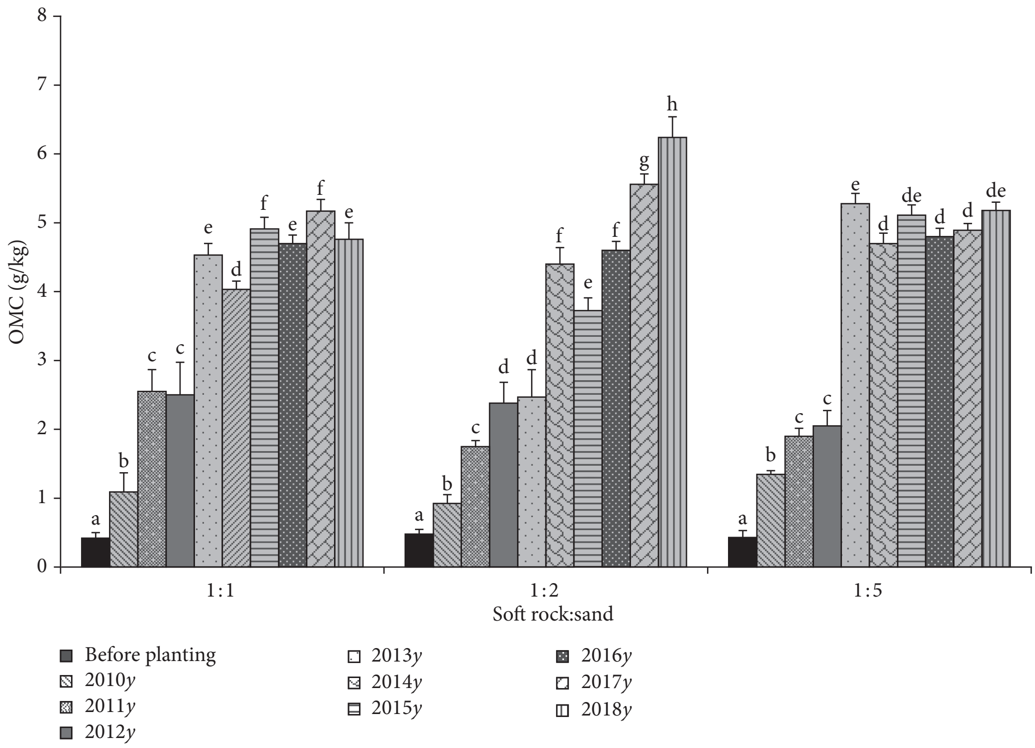

Figure 1: OMC of the compound soil at depths of 0–30 cm over time for soft rock to sand ratios of 1 : 1, 1 : 2, and 1 : 5, respectively. Letters above the bars indicate significant differences (at 0.05 level) between treatments; the small bar shows standard deviation. Columns within different years but with the same letters are not significantly different at $P > 0.05$.

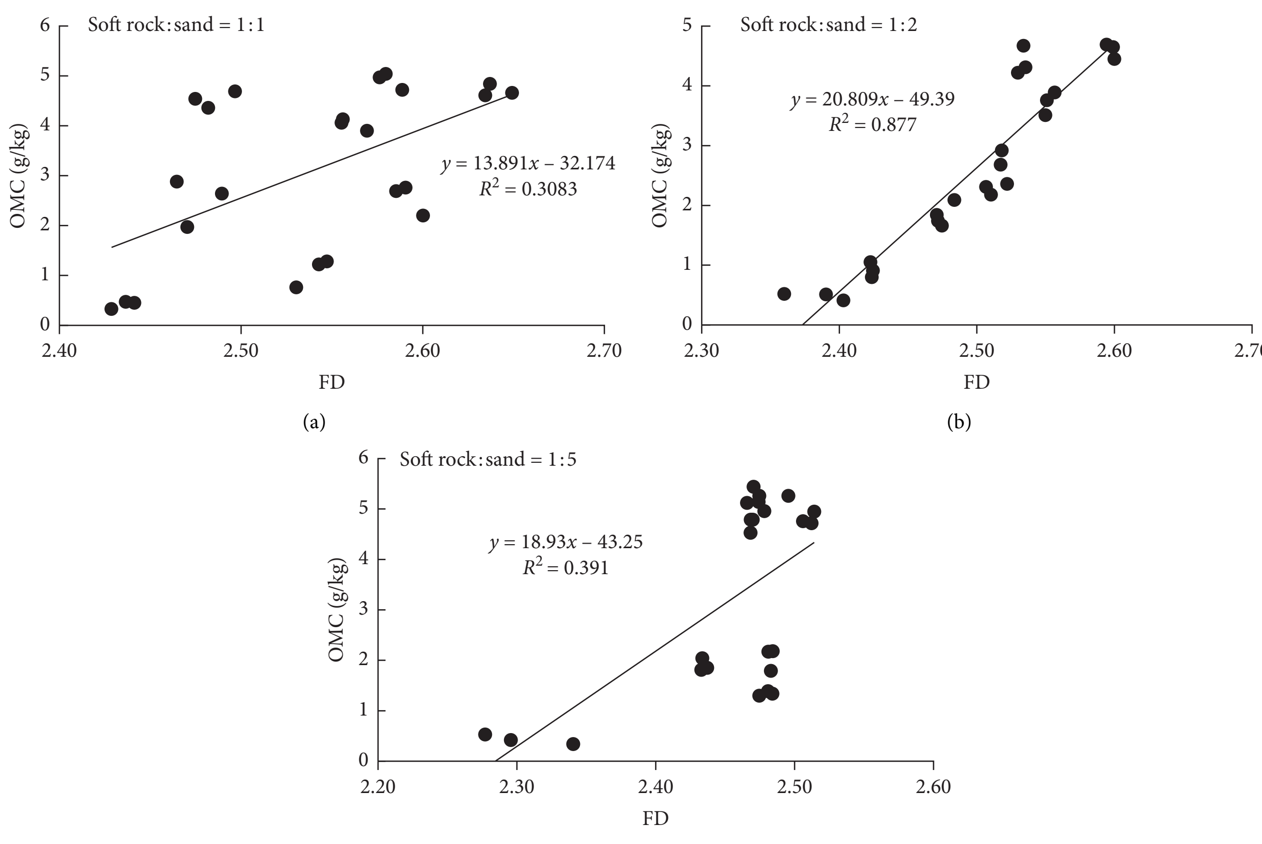

Figure 2: Relationship between FD of compound soil particles and OMC for soft rock to sand ratios of 1 : 1 (a), 1 : 2 (b), and 1 : 5 (c), respectively.

of the compound soil because addition of soft rock material to the aeolian sandy soil increases the content of key soil particle sizes (silt and clay). de Bartolo et al. and Han et al. [9, 15] determined that the secondary clay mineral content in soft rock reached 16.8–46.4%, and the clay content reached 10.3–30.3%. However, more than 95% of sandy land particles are primary minerals of 0.05–1 mm diameter, with clay content as low as 0.8%. Therefore, mixing soft rock and sandy soil introduces clay and colloidal material and improves the texture of the aeolian sandy soil.

Over time, the soft rock grains gradually weathered, decreasing the coarse sand fraction and increasing the clay and silt content. The increasing FD of all three compound soils corresponding to the fine texture was consistent with similar results from Miao et al. [24] and Behzad and Hugh [25]. In contrast, Wang et al. [18] concluded that the FD of soil volume decreased with the number of plantings in the loess soil of vegetable fields; inconsistency may be attributed to the soil parent material. The soil texture of the vegetable field is mainly loamy and sticky clay; the degree of soil development for land used to grow vegetables and sandy land is also quite different. Li and Zhang [26] found that soil developed on a parent material with high degrees of differentiation and weathering showed fine texture and a corresponding large fractal composition. The compound soft rock and sand soil represent a new approach to sand treatment that remains in the primary development stage.

Our finding that the FD of the three compound soil particles was mainly determined by the clay and silt content was similar to that from several other studies [4, 24, 25]. The increase in FD over time, along with a higher fine particulate matter and organic matter content, was due to the differing ability of various soil particle sizes to retain nutrients. The higher the FD, the richer the clay content in the soil and the larger its specific surface area; the strong cohesion and adhesion of clay have a stronger effect on the absorption and fixation of nutrients. Liu et al. [27], Deng et al. [28], and Hua et al. [22] all showed that the FD of soil particles increased with increasing organic matter content, which is consistent with our results. Therefore, in practice, the content of suitable soft rock material in a soil mixture can be increased to enhance the clay and silt content, improving the poor texture of aeolian sand soil to achieve better soil particle gradation and texture, ensuring better soil suitability for crop growth.

5. Conclusions

Changes in FD can represent the development of new compound soil created through the mixture of sandy soil and soft rock in the study area. Over time, the clay and silt content in all three studied proportions increased along with the soil fine particulate matter, i.e., as the texture became finer, the FD increased continuously. Over the study period, the FD and OMC of the 1 : 2 ratio compound soil continuously rose with significant differences between each year, with greater rate of increase than the 1 : 1 and 1 : 5 ratio soils; the 1 : 1 and 1 : 5 ratio compound soils varied greatly but showed overall increase. The 1 : 2 ratio compound soil was determined to be most suitable for maize cultivation as it best developed a composite state of inorganic and organic colloids that improved the soil stability and subsequent agricultural suitability. Moreover, there was a significant positive correlation between the FD of soil particles and the silt, clay, and organic matter content. Silt and clay are the most critical driving factors for soil texture and organic matter improvement in the desertified study area. This engineering method can be applied to the distribution range of soft rock. The technical achievements have been popularized and applied in Mu Us Sandy Land, covering a total area of 2769.74 ha. The project achievements have also played an important role in the construction of forest and grassland, urban green space, and an expressway protection zone.

The FD characterizes the complexity of the soil as a self-organizing system. In this study, we only considered the fractal characteristics of the compound soil particles and their relationship with the grain size distribution and organic matter. However, the formation and development of soil is a long-term process influenced by factors such as parent rock, climate, and vegetation. Future work will further explore the fractal characteristics of compound soil development under different vegetation and environmental conditions at a larger scale. This work has important theoretical and practical significance for understanding the evolutionary mechanism and sustainable use of compound soil and management for agriculture in Mu Us Sandy Land.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

Some authors are employed by Shaanxi Provincial Land Engineering Construction Group Co., Ltd., and all the authors declare that they have no conflicts of interest.

Acknowledgments

The authors are grateful to Professor Jichang Han for his assistance with the experiments and to Professor Jiancang Xie for valuable discussion. They also thank the State Key Laboratory of Eco-Hydraulics in Northwest Arid Region of China for their strong support towards the project. This study was financially supported by the National Key Research and Development Program of China (2016YFC0401409), the National Natural Science Foundation of China (51679188), and the Shaanxi Provincial Land Engineering Construction Group Internal Research Project (DJNY2019-12).

References

[1] A. Abbas, N. Mohammad-Reza, R. Hassan, and A. Hossein, “Fractal dimension of soil aggregates as an index of soil erodibility,” *Journal of Hydrology*, vol. 400, pp. 305–311, 2011.

[2] X. Liu, Z. Li, and P. Li, "Particle fractal dimension and total phosphorus of soil in a typical watershed of Yangtze River, China," *Environmental Earth Sciences*, vol. 73, no. 10, pp. 6091–6099, 2015.

[3] Z. Z. Su, R. Liu, A. M. Liang et al., "Study on soil mechanical composition and organic matter of desertification land in Northwest of Shanxi province," *Research of Soil and Water Conservation*, vol. 25, pp. 61–67, 2018.

[4] X. Wang, H. J. Zhang, J. H. Cheng et al., "Fractal characteristics and related affecting factors of particle size distribution of different forest soil in Simian Mountains, Chongqing," *Journal of Soil and Water Conservation*, vol. 25, pp. 154–159, 2011.

[5] G. Xu, Z. Li, and P. Li, "Fractal features of soil particle-size distribution and total soil nitrogen distribution in a typical watershed in the source area of the middle Dan River, China," *Catena*, vol. 101, pp. 17–23, 2013.

[6] M. Meysam, S. Mahmoud, H. M. Mohammad, and D. Nasser, "Characterizing spatial variability of soil textural fractions and fractal parameters derived from particle size distributions," *Pedosphere*, vol. 29, no. 2, pp. 224–234, 2019.

[7] Y. Ai, Z. Chen, P. Guo et al., "Fractal characteristics of synthetic soil for cut slope revegetation in the purple soil area of China," *Canadian Journal of Soil Science*, vol. 92, no. 2, pp. 277–284, 2012.

[8] K. Liao, X. Lai, Z. Zhou, and Q. Zhu, "Applying fractal analysis to detect spatio-temporal variability of soil moisture content on two contrasting land use hillslopes," *Catena*, vol. 157, pp. 163–172, 2017.

[9] S. de Bartolo, C. Fallico, and G. Severino, "A fractal analysis of the water retention curve," *Hydrological Processes*, vol. 32, no. 10, pp. 1401–1405, 2018.

[10] J. Han, J. Xie, and Y. Zhang, "Potential role of feldspathic sandstone as a natural water retaining agent in Mu Us sandy land, Northwest China," *Chinese Geographical Science*, vol. 22, no. 5, pp. 550–555, 2012.

[11] H. Ni, L. Zhang, D. Zhang, X. Wu, and X. Fu, "Weathering of pisha-sandstones in the wind-water erosion crisscross region on the loess plateau," *Journal of Mountain Science*, vol. 5, no. 4, pp. 340–349, 2008.

[12] N. Wang, J. Xie, J. Han, and L. T. Luo, "A comprehensive framework on land-water resources development in Mu Us sandy land," *Land Use Policy*, vol. 40, pp. 69–73, 2014.

[13] Z. Sun and J. Han, "Effect of soft rock amendment on soil hydraulic parameters and crop performance in Mu Us sandy land, China," *Field Crops Research*, vol. 222, pp. 85–93, 2018.

[14] C. Gülser, "Effect of forage cropping treatments on soil structure and relationships with fractal dimensions," *Geoderma*, vol. 131, no. 1-2, pp. 33–44, 2006.

[15] J. Han, Y. Liu, and Y. Zhang, "Sand stabilization effect of feldspathic sandstone during the fallow period in Mu Us Sandy Land," *Journal of Geographical Sciences*, vol. 25, no. 4, pp. 428–436, 2015.

[16] Q. Zhen, J. Zheng, H. He, F. Han, and X. Zhang, "Effects of pisha sandstone content on solute transport in a sandy soil," *Chemosphere*, vol. 144, pp. 2214–2220, 2016.

[17] H. Wang, J. Han, W. Tong, J. Cheng, and H. Zhang, "Analysis of water and nitrogen use efficiency for maize (*Zea mays* L.) grown on soft rock and sand compound soil," *Journal of the Science of Food and Agriculture*, vol. 97, no. 8, pp. 2553–2560, 2017.

[18] G. L. Wang, S. L. Zhou, and Q. G. Zhao, "Volume fractal dimension of soil particles and its applications to land use," *ActaPedologicaSinica*, vol. 42, pp. 545–550, 2005.

[19] R. A. Pulley, M. Min, and J. Chaplin, "Developing a texture-based soil hydrologic characteristics model and extending this model to predict soil strength characteristics," *Transactions of the ASABE*, vol. 51, no. 2, pp. 485–498, 2008.

[20] E. Perfect and B. D. Kay, "Applications of fractals in soil and tillage research: a review," *Soil and Tillage Research*, vol. 36, no. 1-2, pp. 1–20, 1995.

[21] P. L. Yang, Y. P. Luo, and Y. C. Shi, "Fractal characteristics of soil characterized by particle size distribution," *Chinese Science Bulletin*, vol. 38, pp. 1896–1899, 1993.

[22] R. Hua, X. X. Xu, S. N. Zhang, and C. P. Zhao, "The research of soil particle fractal characteristics of forestland and grassland with different restoration years," *Journal of Soil and Water Conservation*, vol. 30, pp. 206–209, 2016.

[23] L. Zhang, J. C. Han, Z. H. Ma, L. T. Luo, H. Y. Wang, and J. Li, "Texture character study of feldspathic sandstone and sand compound "soil"," *Acta Agriculturae Boreali-Occidentalis Sinica*, vol. 23, pp. 166–172, 2014.

[24] C. Y. Miao, Y. F. Wang, X. Wei, X. Xu, and W. Shi, "Fractal characteristics of soil particles in surface layer of black soil," *Chinese Journal of Applied Ecology*, vol. 18, pp. 1987–1993, 2007.

[25] G. Behzad and D. Hugh, "Fractal dimension of soil fragment mass-size distribution: a critical analysis," *Geoderma*, vol. 245-246, pp. 98–103, 2015.

[26] D. C. Li and T. L. Zhang, "Fractal features of particle size distribution of soils in China," *Soil & Environmental Sciences*, vol. 9, pp. 263–265, 2000.

[27] X. Liu, G. Zhang, G. C. Heathman, Y. Wang, and C.-h. Huang, "Fractal features of soil particle-size distribution as affected by plant communities in the forested region of mountain Yimeng, China," *Geoderma*, vol. 154, no. 1-2, pp. 123–130, 2009.

[28] T. F. Deng, Y. Liu, Q. X. Yan, T. B. He, and A. Q. Gao, "Mechanical composition and soil nutrient characteristics and their relationships in typical Lonicera confusa soil of Guizhou," *Journal of Soil and Water Conservation*, vol. 28, pp. 209–214, 2014.