https://doi.org/10.17221/282/2019-PSE

The long-term performance of composited soil with feldspathic sandstone amendment on sandy soil and its effects on corn yield

Jie Cheng[1,2], Jichang Han[2], Jiancang Xie[1], Huanyuan Wang[2], Zenghui Sun[2], Yichun Du[2], Yingying Sun[2]*

[1]*Xi'an University of Technology, Xi'an, P.R. China*
[2]*Shaanxi Provincial Land Engineering Construction Group Co., Ltd, Xi'an, P.R. China*
**Corresponding author: hanjc_sxdj@126.com*

Citation: Cheng J., Han J.C., Xie J.C., Wang H.Y., Sun Z.H., Du Y.C., Sun Y.Y. (2019): The long-term performance of composited soil with feldspathic sandstone amendment on sandy soil and its effects on corn yield. Plant Soil Environ., 65: 395–400.

Abstract: To estimate the long-term performance and the optimal ratio of feldspathic sandstone with sandy soil, experiments with different ratios of feldspathic sandstone to sandy soil (0:1, 1:1, 1:2 and 1:5 v/v) was conducted. The physical properties as soil texture, water-stable aggregate ($WR_{0.25}$) content, and the organic carbon content of the composited soil for 6 years, and corn yield for 9 years were determined. Our results showed that after the addition of feldspathic sandstone: (1) soil texture was notably improved, changing from sand loamy soil (1:2 and 1:5) to sand loam soil (1:1) and silt sand soil (1:1) over planting time; (2) content of water-stable aggregate ($WR_{0.25}$) significantly increased: $WR_{0.25}$ of treatments 1:1, 1:2 and 1:5 all increased (by 29.26, 31.47 and 11.56%, respectively) compared with that of treatment 0:1; (3) the organic carbon content of the composited soils increased with time in all treatments. After six years of planting, average organic carbon content in treatments 1:1, 1:2 and 1:5 were 1.64, 1.51 and 1.77 g/kg, respectively, which were higher than that of 0:1 treatment; and (4) among the three ratios, treatment 1:2 (12 984 kg/ha) had the highest corn yield, followed by treatment 1:1 (12 040 kg/ha) and 1:5 (11 301 kg/ha). In conclusion, with a good performance, 1:2 was the best ratio of feldspathic sandstone to sand in improving the sandy soil structure of the Mu Us Desert, China.

Keywords: *Zea mays* L.; arable land; sand texture; sand-fixing effect; tillage; organic fertilizer

The recorded sharp decline of cultivated land in China was associated with the rapid advancement of urbanization and infrastructure construction, endangering the national food security. It is therefore important to ensure the achievement of the target of 1.2×10^8 ha cultivated land (Long et al. 2018). The Mu Us Desert is one of four major deserts in China, covering an area of 3.98×10^6 km^2 (Yan et al. 2013), which has sufficient light radiation and relatively abundant precipitation, making it a potential site for arable land excavation (Cheng et al. 2016). However, soil in the desert is severely corroded and sandy, and the ecological environment is fragile. In particular, the Mu Us Desert contains about 1.67×10^6 ha feldspathic sandstone, a deposit that is highly prone to erosion and has been termed as Earth Ecological Cancer (Cheng et al. 2016). Therefore, exploring and developing a comprehensive model using feldspathic sandstone in the Mu Us Desert to remediate sandy soil is urgently needed.

Feldspathic sandstone is composed of quartz (70.5 ± 1.0%), feldspar (16.4 ± 0.5%), muscovite (12.9 ± 1.1%) and hematite (0.2 ± 0.05%) (Bazhenov et al. 1993, Ni et al. 2008). Feldspathic sandstone has high clay content, and water retention capacity and sandy soil has a low clay content, cementation degree poor structure (Wang et al. 2009), high permeability (Bruand et al. 2005) and poor water retention capacity (Fidalski et al. 2013, Reichert et al. 2016). Therefore, feldspathic sandstone and sandy soil are complementary in properties. The combination of feldspathic sandstone and sandy soil at a certain ratio could change the

Supported by the Ministry of Land and Resources Ministry of Public Welfare Industry Research, Project No. 201411008, and by the Basic Research Program of Natural Science in Shaanxi Province, Project No. 2018JM4023.

https://doi.org/10.17221/282/2019-PSE

soil texture and enhance the water holding capacity (Se et al. 2014), which formed a new suitable soil for crop growth. Also, investigations have found that the addition of feldspathic sandstone to sandy soil enhanced the effectiveness of nitrogen and phosphorus fertilizers in the sandy soil (Se et al. 2014, Wang et al. 2017), and had a significant sand-fixing effect (Li et al. 2017). However, previous studies on the physical and chemical properties of the composited soil predominantly focus on the same year or nearly 2 years (Li et al. 2015a), which is largely short for rotation crop planting land. Investigations examining multi-year stability of the physical properties of the composited soil and its crop yield are sparse. Therefore, this research prepared the composited soils by mixing feldspathic sandstone and sandy soil with different ratios, and continuously observed its texture, water-stable aggregate, organic carbon content over 6 years and corn yield over 9 years, to estimate the stability of the composited soil during long term planting and the optimal ratio.

MATERIAL AND METHODS

Study area. Field experiments were carried out in Chuyuan village (108°57'~109°26'E, 34°42'~35°6'N) in Fuping district, Xi'an city, China. The site has an altitude of 375.8~1420.7 m a.s.l., and is characterized by a semi-arid continental climate. Annual average precipitation is 527.2 mm (1960–1995), with precipitation having an uneven distribution with July–September accounts for 49% of total annual rainfall, interannual variability of precipitation is large, and the annual precipitation coefficient of variation (*CV*) is 21.2%. Mean annual temperature is 13.1°C, the highest temperature in summer is 41.8°C and the lowest temperature in winter is –22°C, annual sunshine is 2389.6 h, and annual total radiation is 5187.4 MJ/m^2. The natural condition in this area meet the growth needs of corn (Wei and Zhao 2017).

Experimental design. To simulate the land condition of the mixed layer of feldspathic sandstone and sandy soil in the Mu Us Desert, feldspathic sandstone and sandy soil were collected from Daji Khan village, Xiaoji Khan township, Yuyang district, Yulin city, China. The crusher was used for crushing and screening feldspathic sandstone artificially to ensure that the size of arsenic sandstone was less than 4 cm, and the content of clay, silt, and gravel in feldspathic sandstone was 7.06, 58.09 and 34.85%, respectively.

Feldspathic sandstone and sandy soil were mixed to prepared composited soil. Four treatments with different ratios (0:1, 1:1, 1:2, and 1:5 v/v) of feldspathic sandstone to sandy soil were designed. The main physical and chemical properties of the composited soil were shown in Table 1. Each treatment was repeated 3 times. A total of 12 plots (each plot with 2 m × 2 m) were established. The plots had a random arrangement; the tillage layer (top 30 cm) was the composited soil, 30–70 cm filled with sandy soil, and below 70 cm was the local soil. A wheat-corn rotation model was adopted; the corn cultivar was Wei Ke 702 (Zhengzhou, China). From June 2010 to October 2018, all treatments were conducted by conventional farming and local traditional water and fertilizer management practices (organic fertilizer). After each harvest, the soil of the tillage layer was sampled, and corn yield was recorded.

Soil sampling and measurement. Three soil samples from the 0–30 cm soil layers were randomly collected after maize harvest each year. After homogeneous mixing of each layer, impurities were removed. The soil samples were air-dried in the laboratory and analyzed for soil moisture, water-stable aggregate (Elliott et al. 1986) and soil particle composition (Lu et al. 1999). The corn yield was measured using 4 m^2 samples at the harvest period.

Statistical analysis. Data were analyzed by ANOVA using SPSS v.18.0 (IBM Corp., Armonk, USA), and the least significant method (*LSD*) was selected for the dif-

Table 1. Physical and chemical properties of composited soils

Ratio of feldspathic sandstone to sand	Particle size composition (%)			Texture (USDA)	Bulk density (g/cm^3)	Total N	Total P	Total K	SOC
	sand	silt	clay			(g/kg)			
1:1	50.82	38.12	8.06	sandy loam	1.37	0.44	0.50	22.26	1.31
1:2	68.86	26.01	5.13	sandy loam	1.52	0.54	0.55	23.67	1.51
1:5	79.03	17.35	3.62	sandy soil	1.56	0.65	0.65	25.09	1.72
0:1	95.00	4.10	0.53	sand	1.61	0.75	0.75	26.51	1.93

SOC – soil organic carbon

https://doi.org/10.17221/282/2019-PSE

ferential significance test. All data were plotted using Sigma Plot v.10.0 (Systat Software Inc., San Jose, USA).

RESULTS AND DISCUSSION

Effect of feldspathic sandstone amendment on sandy soil texture. Results indicated that soil texture was markedly changed after the addition of feldspathic sandstone (Figure 1). With the addition of feldspathic sandstone, the key fraction contents (clay and silt) in the sandy soil gradually increased, and clay content in treatments of 1:1, 1:2 and 1:5 ratios were 4.60 ± 2.15, 3.34 ± 1.62 and 3.08 ± 1.40%, respectively. Compared with pure sandy soil (0:1 treatment), the greatest increase in clay-sized content (62.13%) was recorded in the treatment 1:1; treatments 1:2 and 1:5 also increased by more than 40%. The silt-sized content of treatments 1:1, 1:2 and 1:5 was 31.14 ± 13.72, 21.72 ± 7.38 and 19.80 ± 6.20%, respectively. Compared with the sandy soil (0:1 treatment), silt-sized content in the composited soils all increased by more than 70% and the 1:1 treatment recorded the greatest increase (81.93%).

The content of sand-sized particles in the sandy soil did not change with cultivation year. But the content of silt-sized particles in treatments 1:2 and 1:5 increased with the increase of cultivation time. 1:2 treatment recorded a change from loamy sand to a sandy loam after 4-year of cultivation. The content of silt-sized particles in 1:1 treatment recorded the greatest change with planting time increasing; clay content in this treatment was also recorded to be the greatest. After one year of planting, soil texture of 1:1 treatment changed from loamy sand to sandy loam and became silty soil after 5-year of planting. By adding feldspathic sandstone to sandy soil, the sand texture gradually changed from a sand-loamy soil (1:2, 1:5) to a sandy loam soil or silt and soil (1:1).

As one of the basic physical properties, soil texture is the combination of particles of different sizes and diameters in soil and is closely related to soil aeration, water retention, fertilizer retention and farming difficulty (Weil and Brady 1996). Addition of feldspathic sandstone significantly improved silt and clay contents, effectively improved sand texture. These may be due to the high clay content as 10.3~30.3% of feldspathic sandstone (Peng et al. 2018). These characteristics are complementary to that of feldspathic sandstone. Therefore, after the addition of feldspathic sandstone, silt, and clay in the feldspathic sandstone fill the pores of the sandy soil, which changes its silt-size composition and improves the sand texture. Also, the higher the ratio of feldspathic sandstone to sand, the better the improvement of desert texture. So, the treatment 1:1 performed better than 1:2 and 1:5, the clay structure was improved, and the content of silt and clay was significantly increased. With the increase of planting

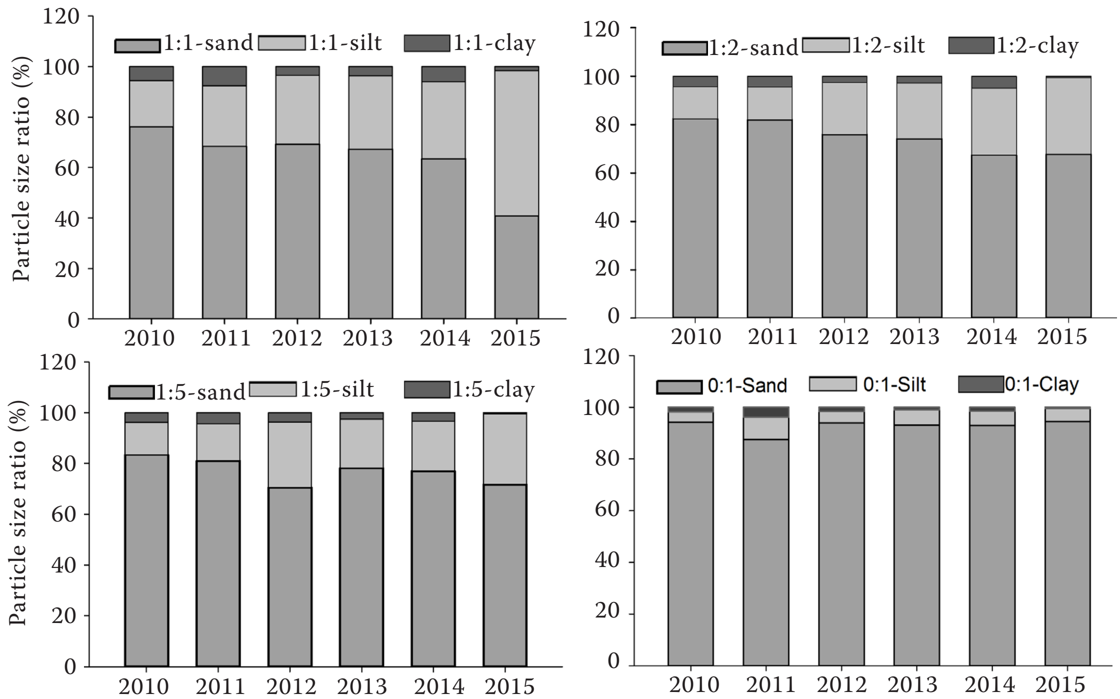

Figure 1. Changes in soil texture of improved sandy soil with the addition of feldspathic sandstone

https://doi.org/10.17221/282/2019-PSE

year, crop roots further improved the structure of the sandy soil, thereby improving the soil texture.

Effect of adding feldspathic sandstone on stable water aggregates of sandy soil. The addition of feldspathic sandstone significantly increased the > 0.25 mm water-stable aggregate ($WR_{0.25}$) content in the sandy soil (P < 0.05, Figure 2). Over the 6-year planting period, $WR_{0.25}$ contents for 1:1, 1:2, 1:5 and 0:1 treatments were 16.2~19.03, 19.35~29.33, 17.56~32.99 and 17.42~27.13%, respectively. Contents in treatments 1:1, 1:2 and 1:5 increased by 29.26, 31.47 and 11.56% compared to treatment 0:1, respectively.

The content of stable water aggregates with a diameter greater than 0.25 mm ($WR_{0.25}$) can reflect soil quality and erosion resistance, and they can contribute to soil stability (Angers 1992, Chen et al. 2008). Findings by Oades and Waters (1991) showed that organic cementation plays an important role in the formation of stable water aggregates. Desert soil contains lots of primary minerals and only a few secondary minerals, especially clay minerals and montmorillonites (accounting for 6.5%), with clay content being only 0.85% (Zhang et al. 2015). Feldspathic sandstone is rich in clay minerals such as calcium montmorillonite, montmorillonite and glimmer ton, which can be as high as 5.4~56%. When feldspathic sandstone is mixed with sandy soil, the large volume of colloidal substances in feldspathic sandstone cosmic promotes the formation of aggregates. At the first two planting years, $WR_{0.25}$ in treatment 1:1 was much higher than other treatments, which was due to its high content of feldspathic sandstone. In general, with organic fertilizers were continuously applied, the crop root exudates, soil microbe biomass, and metabolites increased over planting time; they promoted the formation of soil particle aggregate (Ye et al. 2018). $WR_{0.25}$ in treatment 1:2 increased continually at the first two planting years, and was higher than in treatment 1:1 after the third year. This might be because soil structure in treatment 1:2 was more suitable for crop and microbial survival, secretion of which facilitated the formation of $WR_{0.25}$. Soil texture in treatment 1:5 was loamy with less colloidal material, so the $WR_{0.25}$ content was only obviously improved after 5 years of planting. Our results indicated that the ratio (i.e., feldspathic sandstone content) was the material basis for the formation of aggregates. Besides, planting as a kinetic process of agglomeration promote the formation of aggregates. Both the compounding ratio and planting time are important factors affecting the content of water-stable large aggregate in the composited soil.

Effect of adding feldspathic sandstone on organic carbon content in sandy soil. Results indicated that the addition of feldspathic sandstone significantly increased organic carbon content in the sandy soil (P < 0.05, Figure 3). After six years of planting, the organic carbon content of the tillage layers in treatments 0:1, 1:1, 1:2 and 1:5 were 0.39 ± 0.044, 1.64 ± 0.15, 1.51 ± 0.13 and 1.77 ± 0.082 g/kg, respectively. Organic matter is the main determinant of soil fertility, nutrient storage, and microbial and enzymatic activities (Ashagrie et al. 2005). We found the addition of feldspathic sandstone significantly increased the content of organic carbon in the sandy soil. Organic carbon content in the tillage layer increased with planting year in all composited ratios. In the first three years, no significant difference was recorded among the different composited ratios. At the third year, the organic carbon content in 1:1 and 1:5 increased quickly while slowly in treatment 1:2. Also, soil organic carbon content in 1:1 and 1:5 treatments decreased in the 5th year and significantly increased to 3.03 ± 0.10 and 2.96 ± 0.087 g/kg, respectively, at 2015 with the application of organic fertilizer. When the ratio of feldspathic sandstone and sandy soil was 1:2, organic carbon content kept above 1.01 g/kg at the

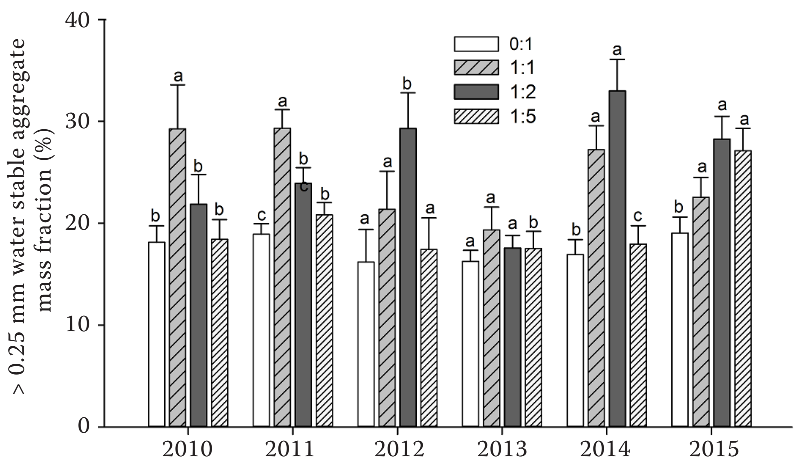

Figure 2. Variation of water stable aggregates of improved sand soil with the addition of feldspathic sandstone

https://doi.org/10.17221/282/2019-PSE

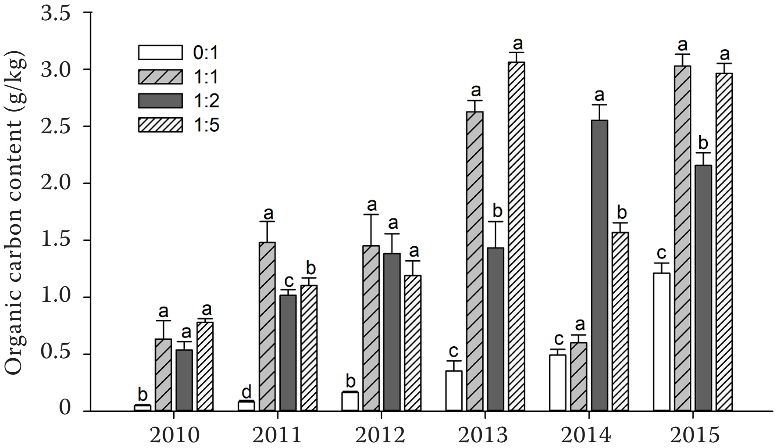

Figure 3. Variation of organic carbon content in improved sand soil with the addition of feldspathic sandstone

first four years, and 2.16 g/kg at the latter two years. Organic carbon content in sandy soil (treatment 0:1) changed the slowest and was 1.21 g/kg only after six years of planting. While in the composited soil it had been above 1 g/kg after two years of planting. The results of water-stable aggregate content suggested that aggregate structure was more stable when the composited ratio was 1:2, and that organic carbon retention and aggregate formation promoted each other. Higher organic carbon content indicated high soil fertility; organic carbon can enhance soil particle cementation and facilitate the formation of soil aggregates (Luo et al. 2007). Therefore, the organic carbon content in the composited soil was the most stable in the tillage layer of treatment 1:2. Also, organic carbon content increased with the increase of tillage year, which may be due to the carbon sequestration by roots. Li et al. (2015b) recorded that long-term conservation tillage can increase soil organic carbon content, which is consistent with our results. With the increase of planting year, organic carbon fixed by crops exporting to roots and exuding to the soil layer increase (Li et al. 2015b).

Effect of adding feldspathic sandstone on corn yield in sandy soil. Corn yield under different ratios of feldspathic sandstone to sand (Figure 4) showed different magnitudes of increase over time; treatment 1:2 recorded the greatest increase. Averagely, corn yield showed an order of 1:2 > 1:1 > 1:5, with values of 12 984, 12 040 and 11 301 kg/ha, respectively. After 9 years of planting, corn yield increased by 0.6, 1.0, and 0.3 times, respectively, compared with the first year.

The retention of organic carbon matters and the formation of soil aggregates complement each other. After the addition of feldspathic sandstone, aggregates and organic carbon contents of the composited soil were recorded to be significantly higher than that of sandy soil. This increase in organic carbon content was beneficial to the formation and stability of soil structure; the stable soil structure then contributed to the increase of corn yield (Unger 1997, Olk and Gregorich 2006). Average corn yield in treatment 1:2 was the highest, which might be due to its moderate content of clay. Moderate clay content facilitates the formation of more water-stable aggregates, of the most

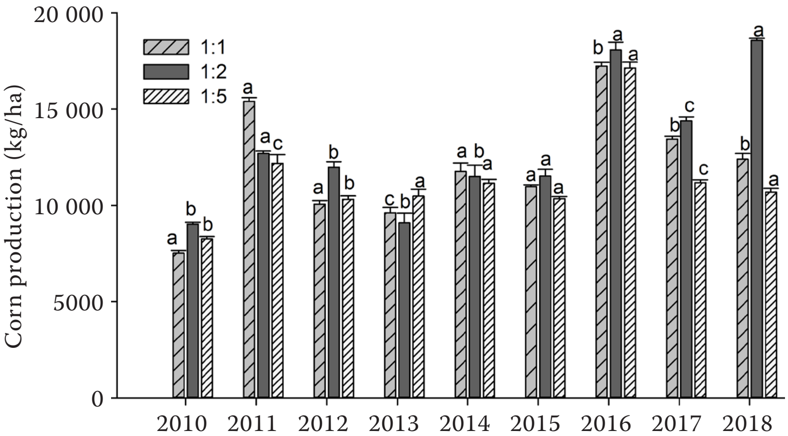

Figure 4. Yield variation of feldspathic sandstone improved sandy soil under different ratios

https://doi.org/10.17221/282/2019-PSE

stable soil structure and the fastest soil ripening. Also, annual corn yield displayed significant differences among different years, even in the same treatments. It might be related to the difference in rainfall and other environmental conditions.

Therefore, 1:2 is the best ratio to remediate sandy soil. At ratio 1:2, the structure of sandy soil will be effectively improved, organic carbon content will be enhanced, and corn yield will be significantly increased.

REFERENCES

Angers D.A. (1992): Changes in soil aggregation and organic carbon under corn and alfalfa. Soil Science Society of America Journal, 56: 1244–1249.

Ashagrie Y., Zech W., Guggenberger G. (2007): Soil aggregation, and total and particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia. Soil and Tillage Research, 94: 101–108.

Bazhenov M.L., Chauvin A., Audibert M., Levashova N.M. (1993): Permian and Triassic paleomagnetism of the southwestern Tien Shan: Timing and mode of tectonic rotations. Earth and Planetary Science Letters, 118: 195–212.

Bruand A., Hartmann C., Lesturgez G. (2005): Physical properties of tropical sandy soils: A large range of behaviors. In: Proceedings of the Management of Tropical Sandy Soils for Sustainable Agriculture: A Holistic Approach for Sustainable Development of Problem Soils in the Tropics. Khon Kaen, Thailand, 148–158.

Cheng J., Han J.C., Wang H.Y. (2016): Study on the mechanism of sand fixation by Mu Us desert Arsenic feldspathic sandstone. Journal of Soil and Water Conservation, 30: 124–127.

Chen Z., Jiang X.J., Luo H.Y., Li N. (2008): Distribution of soil microbial biomass within soil water-stable aggregates and the effects of tillage. Acta Ecologica Sinica, 28: 5964–5669.

Elliott E.T. (1986): Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. Soil Science Society of America Journal, 50: 627–633.

Fidalski J., Tormena C.A., Alves S.J., Auler P.A.M. (2013): Influence of sand fractions on water retention and availability in Caiuá and Paranavaí sandstone formations. Revista Brasileira de Ciencia do Solo, 37: 613–621.

Li J., Han J.C., Zhang W.H., Wang H.Y. (2015a): Physical properties and correlation spectral properties of arsenic feldspathic sandstone and sand complex soil. Journal of Triptycene Crops, 35: 394–401.

Li J., Wu H.J., Wu X.P., Cai D.X., Yao Y.Q., Lv J.J. (2015b): Long-term protective tillage to increase soil macroaggregate content and agglomerate organic carbon. Journal of Plant Nutrition and Fertilizer, 22: 378–386.

Li Y.R., Fan P.C., Cao Z., Chen Y.F., Liu Y.S., Wang H.Y., Liu H.H., Ma F., Wang H. (2017): Sand-fixing effect and microscopic mechanism of Mu Us desert Arsenic feldspathic sandstone and sand compounding farmland. Journal of Desert Research, 37: 421–430.

Long H.L., Zhang Y.N., Tu S.S. (2018): Land consolidation and rural vitalization. Acta Geographica Sinica, 73: 1837–1849.

Lu R.K. (1999): Soil Agrochemical Analysis Method. Beijing, China Agricultural Science and Technology Press.

Luo Y.J., Wang F.F., Gao M. (2007): Effects of different tillage systems on active organic matter and carbon storage management index of purple paddy soil. Journal of Soil and Water Conservation, 21: 55–59.

Ni H.B., Zhang L.P., Zhang D.G., Wu X.F. (2008): Weathering of pisha-sandstones in the wind-water erosion crisscross region on the Loess Plateau. Journal of Mountain Science, 5: 340–349.

Oades J.M., Waters A.G. (1991): Aggregate hierarchy in soils. Australian Journal of Soil Research, 29: 815–828.

Olk D.C., Gregorich E.G. (2006): Overview of the symposium proceedings, 'meaningful pools in determining soil carbon and nitrogen dynamics'. Soil Science Society of America Journal, 70: 967–974.

Peng B., Sun Y.Y., Sun X.B. (2018): Study on the mineral composition of Mu Us desert Arsenic feldspathic sandstone. Land Development Engineering Research, 15: 29–34.

Reichert J.M., Rodrigues M.F., Bervald C.M.P., Kato O.R. (2016): Fire-free fallow management by mechanized chopping of biomass for sustainable agriculture in eastern Amazon: Effects on soil compactness, porosity, and water retention and availability. Land Degradation and Development, 27: 1403–1412.

Se X.Y., Zhang X.C., We X.R. (2014): Water absorption and water retention characteristics of a moderate amount of Arsenic feldspathic sandstone improved aeolian sandy soil. Transactions of the Chinese Society of Agricultural Engineering, 30: 115–123.

Unger P.W. (1997): Aggregate and organic carbon concentration interrelationships of a Torrertic Paleustoll. Soil and Tillage Research, 42: 95–113.

Wang Y., Zhang J.Y., Zhang X.C., Long Y.(2009): Response of soil nutrients to wetland degradation in Mu Us Sand Land. Acta Agrestia Sinica, 2: 250–254.

Wang H.Y., Han J.C., Tong W., Cheng J., Zhang H. (2017): Analysis of water and nitrogen use efficiency for corn (*Zea mays* L.) grown on soft rock and sand compound soil. Journal of the Science of Food and Agriculture, 97: 2553–2560.

Weil R.R., Brady N.C. (1996): The Nature and Properties of Soils. 15th Edition. Essex, Pearson Education, 740.

Wei S.M., Zhao X. (2017): Improvement and time effect of arsenic feldspathic sandstone on aeolian sand properties. Soil and Water Conservation Research, 28: 16–21.

Yan F., Wu B., Wang Y. (2013): Temporal and spatial variation characteristics of vegetation growth in Mu Us desert from 2000 to 2011. Geographical Science, 33: 602–608.

Ye X.F., Li Z.P., Yu X.N., Wang Y., Liu H., Dai X.Q., Cheng C.X., Zhang Y.H. (2018): Effects of fertilization measures on soil aggregates and soil carbon pool in tobacco fields. Soil Science Bulletin, 49: 385–391.

Zhang L., Han J.C., Wang H.Y., Ma Z.H. (2015): Variation of particle size composition after arsenic feldspathic sandstone and aeolian sandy soil compounding. China Soil and Water Conservation Science, 13: 44–49.

Received on May 22, 2019
Accepted on July 30, 2019
Published online on August 20, 2019