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EFFECTS OF FELDSPATHIC SANDSTONE ON MECHANICAL AND MINERAL COMPOSITION, WATER STORAGE AND CRON (*ZEA MAYS* L.) YIELD OF SANDY SOIL IN MU US DESERT, CHINA

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Abstract

Effects of feldspathic sandstone as soil amendment on mechanical and mineral composition, water storage and yield of corn (*Zea mays* L.) were investigated. The experiment was carried out in a field containing sandy soil in Mu Us Sandy Land of China in between 2012 and 2014. In the first year of the experiment, treatments included four rates of feldspathic sandstone to sandy soil in volume. After feldspathic sandstone and sandy soil compounding, the texture characteristics of compound soil changed gradually from sand to silt loam and the content of montmorillonite, goeschwitzite and kaolinite gradually increased. The water storage of the surface soil (30 cm) showed an increasing trend of polynomial function with y = 8.286 × 0.705 (y for water storage, %, x for four kinds of treatments, x = 1, 2, 3, 4). Grain yield of the corn crop increased from 67.8-160.1%. The treatment with a rate of 1 : 1 (feldspathic sandstone to sandy soil in volume) had the great effect on soil physical properties averaged over the three years. The treatment with rate of 1 : 2 had the greatest effect on crop performance. Feldspathic sandstone showed great prospect for improving soil physical properties and crop yield in Mu Us Sand Land and deserve further study.

Introduction

Desertification is one of the most critical types of land degradation and is being widely recognised as a serious threat to arid environments worldwide (Veron *et al.* 2006, Li *et al.* 2018). Mu Us Sandy Land is one of four major sandy land areas in China with 3.98 × 106 ha (Sun and Han 2018). Due to the lack of water resource and unreasonable land reclamation, the land desertification and the low productivity of crops have been considered very serious issues in this region (Liu *et al.* 2010). Therefore, via improving the capacity of soil to store water in the crop fields has greater importance for the sustainable development and ecological protection of Mu Us desert. Meanwhile, the research conclusions can be applied to another desert or semi-arid and arid region.

There is an area of more than 1.67 × 106 ha feldspathic sandstone surrounding Mu Us desert (Ni *et al.* 2008). These feldspathic sandstones were formed during the Permian, Mesozoic, Triassic, Jurassic and Cretaceous periods (Bazhenov *et al.* 1993, Martin *et al.* 1999). Since these sandstones had experienced the history of low compaction and low cementation they are highly in compact in nature (Zhang *et al.* 2009).

Some researchers found that the sand mixed with the feldspathic sandstone can significantly increase the water storage, because the feldspathic sandstone had high content of silt and clay with high water retention capacity (Han *et al.* 2012). The feldspathic sandstone can be used as soil amendments for sandy soil in the Mu Us desert. The compound soil prepared by feldspathic sandstone with sand, supports a favourable environment for crops growth. However, due to the different ratios of feldspathic sandstones to sand, the water storage and crop yield of compound

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soil are seriously impacted. Therefore, in order to improve the effect of water storage and crop field for compound soil, this study has been undertaken to evaluate the effect of different rates of feldspathic sandstone amendments to sand.

Materials and Methods

The experimental area for the present research is situated in Dajihan village, Xiaojihan Township, Yuyang district, Yulin city, northern Shaanxi Province, China. The geographical position is 109°28'58" - 109°30'10" E and 38°27'53" - 38°28'23" N, located in the southern edge of the Mu Us Desert, with an altitude of 1206 - 1215 MSL. The study area belongs to the typical warm temperate monsoon climate. The average annual temperature is 8.1°C with an annual average frost-free period of 154 days. The annual precipitation ranged from 250 - 440 mm with an annual average value 413.9 mm. Off the total precipitation, 65% occur from June to September in every year. The annual average sunshine is 2879 hrs and the sunshine ratio is 65%. The total annual radiation had been calculated as 606. 94 kJ/cm. The dryness index ranges from 1.0 - 2.5 and the wind speed is higher than 5 m/s.

The experimental design consisted of four ratios of feldspathic sandstone to sandy soil by volume: 0 : 1, 1 : 1, 1 : 2 and 1 : 5. These compound soils were loaded into four test fields (10 ×10 m) and the bulk density of compound soil measured was 1.3 g/cm^3. The experimental sample was taken from the 0 - 30 cm surface layer.

The mechanical composition of all soil samples was measured by the laser grain size analyzer (Malvern Panalytical, England, Mastersizer 3000). The wet method and manual measurement and three replicate measurements were done for each sample.

The mineral composition of all soil samples was measured by the phase analysis of X-ray diffraction (Rigaku corporation, Japan, D/max-TTRIII). The soil sample was divided into < 10 and < 2 μm particles by water suspension method. Samples with the particle size of < 10 μm were used to determine the total relative content of each mineral in the sample. Samples with a particle size of < 2 μm was used to determine the relative content of various clay minerals versus total clay minerals.

The water storage of all soil samples was measured by the drying method (Dugan *et al*. 2010, Koide *et al.*). The soil sample was collected directly into aluminum boxes which were quickly brought back to the laboratory for weighing. In the laboratory the samples were placed in an oven to dry at 105ºC for 24 hrs. After drying each sample was weighed again to calculate the water storage using following equation.

$$\theta(\%) = \frac{m_1 - m_2}{m_2 - m} \times 100$$

$$\text{WS} = \theta \times \rho \times H \times 10$$

where, WS is the water storage of soil; m1 is the weight of the aluminum box and the humidified soil (g); m_2 is the weight of aluminum box and the dry soil (g); m is the weight of aluminum box (g); θ is the bulk density of soil (g/cm^3) and H is the thickness of soil (cm).

A 10 m^2 area of four test field was harvested by hand at maturity to measure corn grain yield in 2012, 2013 and 2014. Tillage consisted of spring ploughing at about 30 cm depth. Seeds of the corn were planted manually at the middle of May in each of the three years. In 2012, about 60 days of rock application to soil, seeds were sown. The corn variety was XianYu335, the seeding depth was about 5 cm, the row spacing was 60 cm, and the planting density was 65,000 plants/ha. The Xian Yu335 was widely used in local corn production with moderate sensitive to water deficit. Compound fertilizer (90 kg N/ha, 40 kg P/ha and 75 kg K/ha) was applied into 20 cm deep furrows and covered with soil using a fertilizer applicator when seeding. Urea was applied at 187 kg N/ha at the corn jointing stage as the local applied levels of fertilizer management. Weed control was by manual hoeing when required. Harvest was in the late September approximately 130 days after sowing.

Results and Discussion

The distribution of grain size of the compound soil, feldspathic sandstone and sandy soil is shown in Fig.1. When all the feldspathic sandstone is (1 : 0), the content of coarse silt (0.01 - 0.05 mm) is the largest, followed by the fine silt (0.002 - 0.005 mm) and the medium (0.005 - 0.01). The content of coarse clay (0.001 - 0.002 mm) and fine clay (< 0.001 mm) is less. The content of sand (> 0.25 mm) is very few. When all is sandy soil, the content of coarse sand (0.25 - 1 mm) is the largest, followed by the fine sand (0.05 - 0.25 mm), and the content of silt (0.002 - 0.05 mm) is very small, only 4.05%. The content of clay is less than 1%.

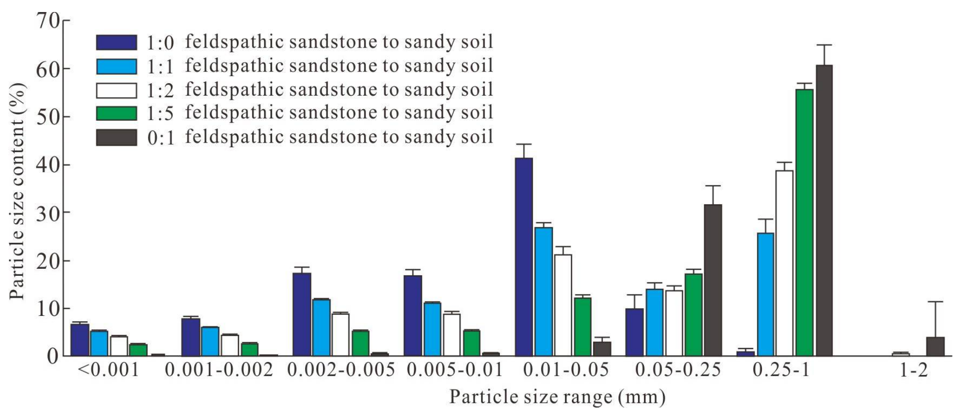

Fig. 1. Particle size distribution range of feldspathic sandstone and sandy soil compound soil.

In the three ratios (1 : 1, 1 : 2 and 1 : 5), the compound soil has the largest content of coarse sand (0.25 - 1.00 mm), and the content of fine sand (0.05 - 0.25 mm) and coarse silt (0.01 - 0.05 mm) is second. When the grain size is < 0.05 mm, the content followed a trend 1:0 > 1 : 1 > 1 : 2 > 1 : 5 > 0 : 1. When the grain size is > 0.05 mm, the trend of variation looked 1 : 0 < 1 : 1 < 1 : 2 < 1 : 5 < 0:1. It can be easily found from Fig. 1 that the character above mentioned is caused by the large content of sand (> 0.05 mm) in the sandy soil and the large content of silt (< 0.05 mm) in the feldspathic sandstone.

Fig. 1 shows that with the increase of the content of feldspathic sandstone, the content of the key grain (silt and clay) increased linearly in the compound soil. The relationship expression of silt is $y = 64.04x + 10.41$, R2 = 0.963, and the relationship expression of clay is $y = 13.31x + 2.42$, R2 = 0.887 (y is the content of corresponding particle, %, x is the content of feldspathic sandstone, R is the coefficient of association). The texture characteristics of compound soil changed gradually from sand to sandy loam to loam and to silt loam.

Fig. 2 is the probability cumulative curve and frequency distribution curve of compound soil. It can be found that the grain size distribution of feldspathic sandstone was wide, and the frequency distribution has no obvious high peak, and the cumulative curve has no obvious steep slope. These indicate that the sort of feldspathic sandstone is poor, and no grain size dominates.

The grain size of sandy soil in Mu Us land is mainly distributed between 0.05 and 1 mm. Overall, the grain of sandy soil is coarse. The frequency distribution curve has a very narrow peak distribution. The cumulative curve has obvious steep slope. These indicate that the sort of sandy soil is well.

In the compound soil with three ratios (1 : 1, 1 : 2 and 1 : 5), the frequency distribution curve is divided into 2 parts (Fig. 2). With the increase of feldspathic sandstone, the content of fine particles (< 0.05 mm) increases gradually, and the content of coarse particle (> 0.05 mm) gradually decreases. The cumulative curve of the compound soil shows a diagonal trend. It shows that the homogenization of sandy soil is improved after the addition of the feldspathic sandstone in the sandy soil, and the distribution of grain size is expanded.

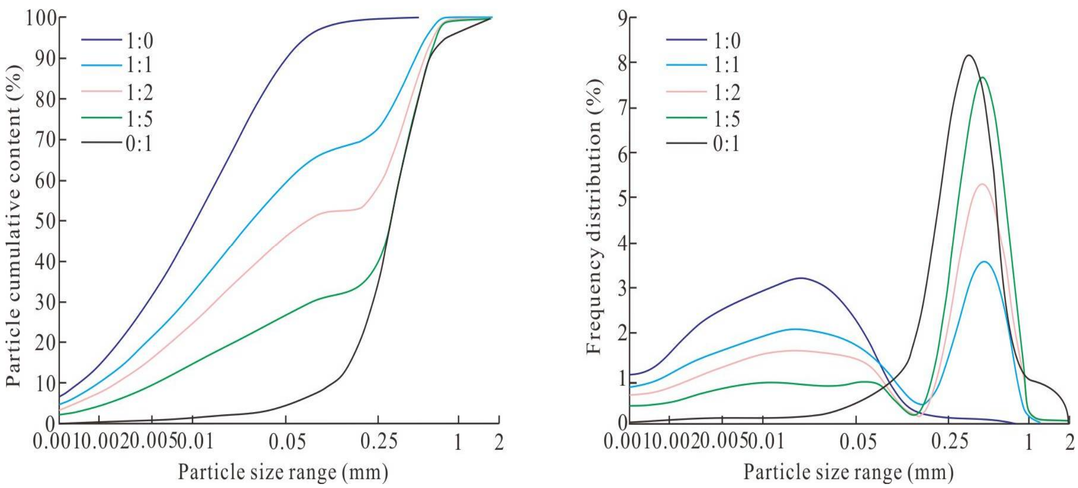

Fig. 2. Particle accumulative curve and frequency distribution curve of feldspathic sandstone and sandy soil compound soil.

The mineral composition of the compound soil, feldspathic sandstone and sandy soil is shown in Table. 1. the compound soil, feldspathic sandstone and sandy soil are composed of quartz, orthoclase, plagioclase calcite, pyrite, montmorillonite, kaolinite, goeschwitzite. The montmorillonite, kaolinite and goeschwitzite are the secondary mineral and colloidal mineral, which are key materials for crop (Mi *et al.* 2017). The feldspathic sandstone contains 15.6% secondary minerals, and the sandy soil contains only 6.5% secondary minerals. With the increase of feldspathic sandstone in the compound soil, the content of secondary mineral in the compound soil gradually increase from 6.5 - 11.5%. In the secondary mineral, the montmorillonite and kaolinite have strong water absorption and swelling ability (Tahir and Marschner 2016). They can increase the soil water storage signally.

The feldspathic sandstone greatly improves the water storage of sandy soil. With the increase of the proportion of feldspathic sandstone, the water storage of compound soil in the surface layer (30 cm) increases. The formula is $y = 8.286 x \ 0.705$, $R = 0.995$ (y is the amount of water storage, x is the treatment, x = 1,2,3,4, R is the coefficient of association). According to the treatment of compound soil (1 : 5, 1 : 2, 1 : 1), the growth ratio of water storage is 71.52, 29.67 and 18.15%. It can be found that the largest increase in water storage is the 1 : 5 ratios of feldspathic sandstone added into sandy soil. The larger growth rate in water storage is the 1 : 2 ratios of feldspathic sandstone added into sandy soil. It shows that the feldspathic sandstone has great water effect. But the amount of feldspathic sandstone should not exceed that of sandy soil, because it is beneficial to control sandy soil and increase the water storage of the compound soil.

Table 1. Mineral composition of the compound soil, feldspathic sandstone and sandy soil.

Name	Quartz	Orthoclase	Plagioclase	Calcite	Pyrite	Montmo-rillonite	Goesch-witzite	Kaolinite
Feldspathic sandstone	32.9	8.8	30.2	12.1	0.5	3.3	9.6	2.7
Sandy soil	36.5	13.6	38.2	5.2	/	1.8	3.9	0.8
1 : 1 compound soil	35.7	10.2	35.2	7.65	0.2	2.55	6.75	1.75
1 : 2 "	34.3	13	35.5	7.2	0.13	2.5	5.87	1.5
1 : 5 "	35.9	12.8	37.1	6.0	0.1	2.1	4.7	1.3

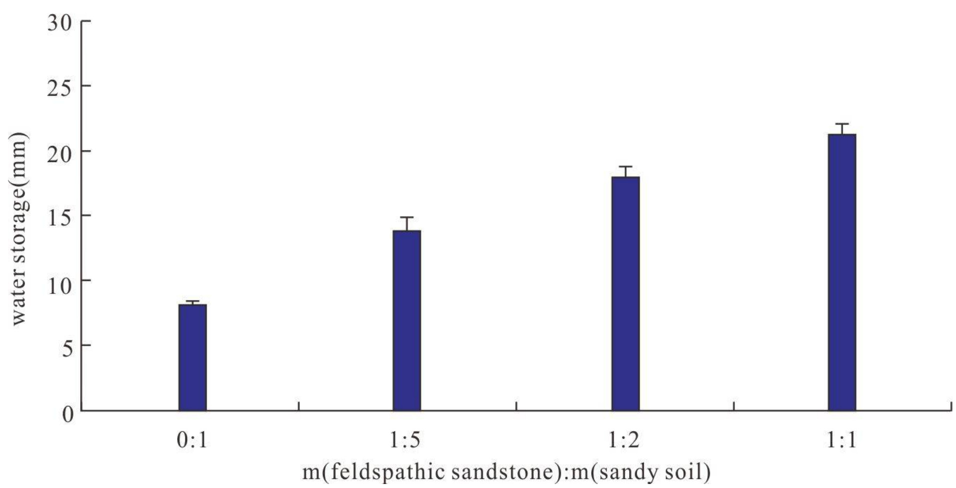

Fig. 3. Water storage in different ratios of feldspathic sandstone to sandy soil.

The mineralogical structure of feldspathic sandstone allows it to absorb a large amount of water rapidly under sufficient water conditions, and slowly release water into the soil for crop uptake under drought conditions (Mi *et al.* 2017). The 1 : 1 treatment had highest soil water storage, but not the higher the water storage, the better the crop. Although soft rock increased water storage, the additional stored water was not always crop available. This might be one of the reasons for the increased yield up to a certain level of rock application rate to the soil. This was comparable to other studies where soil amendment increased soil water storage but not relative soil water content in Orthosiphonaristatus and Lupinusalbus (Nguyen *et al.* 2009, Farrell *et al.* 2013).

The corn yield of all soil amendment treatments is significantly greater than the corn yield of the sandy soil for three years (Fig. 4). The compound soil increases the corn yield by 88.9 - 103.7, 67.8 - 89.7, and 137.5 - 160.1%, respectively in 2012, 2013 and 2014 over that for the sandy soil. The 1 : 2 compound soil has the highest core yield with 6203.58, 8547.26 and 5218.76 kg/ha in 2012, 2013 and 2014, respectively.

This study shows that the feldspathic sandstone significantly increases the corn yield of sandy soil. This was consistent with other researches (Dorraji *et al.* 2010, Xu *et al.* 2015, Miščević and

Vlastelica 2017) that showed synthetic or natural soil amendments both significantly increased crop yield in sandy soils in semi-arid regions. However, some studies showed that the amendments even had negative effect on crop performance under different soil and environment conditions (Ingram and Yeager 1987). In this experiment, the three ratios treatments increased total grain yield in the three years by 3146, 3471 and 2840 kg/ha. The 1 : 2 treatment was optimum in the three years. This is due to lower rainfall. This contributed to increased plant water uptake and enhanced crop performance. Under limited rainfall, the feldspathic sandstone held the water which reduced loss by evaporation and consequently such as in 2014. Application of feldspathic sandstone provided a viable strategy for farmers to increase crop yield and economic return and at the same time, promote sustainable development of agriculture production in Mu Us Sandy desert.

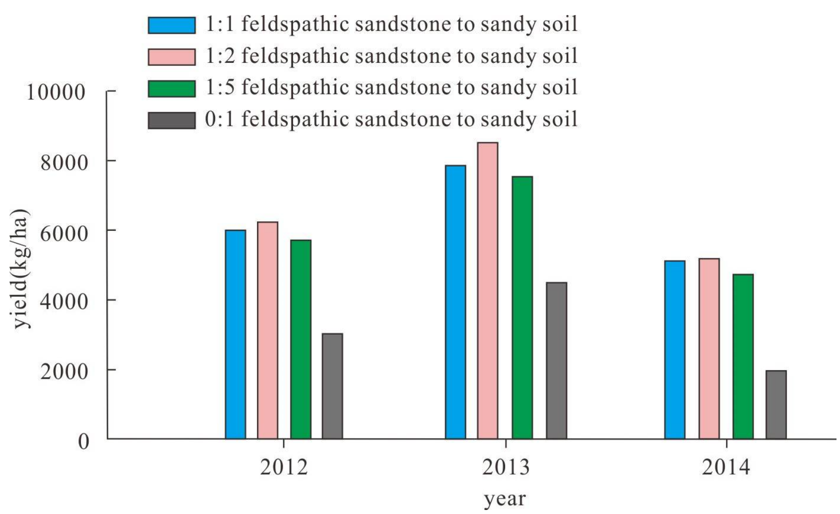

Fig. 4. Grain yield of the compound soil in 2012, 2013 and 2014.

The feldspathic sandstone as a soil amendment can improve the mechanical and mineral composition of sand soil in relatively drought periods, and increased soil water storage and crop yield. In the four ratios (1 : 5, 1 : 2, 1 : 1 and 0 : 1) of feldspathic sandstone to sandy soil in volume, the texture characteristics of compound soil changed gradually from sand to silt loam, and the content of montmorillonite, goeschwitzite and kaolinite gradually increase. The water storage of surface (30 cm) presented the kind of increase trend of polynomial with y = 8.286 x 0.705 (y for water storage, %, x for four kinds of treatments, x = 1, 2, 3, 4). Grain yield increases ranged from 67.8 - 160.1%. The treatment with rate of 1 : 1 (feldspathic sandstone to sandy soil in volume) had the great effect on soil physical properties averaged over the three years. The treatment with rate of 1 : 2 had the great effect on crop performance.

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