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Effect of soft rock amendment on soil hydraulic parameters and crop performance in Mu Us Sandy Land, China

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ABSTRACT

Effect of soft rock as soil amendment on soil moisture, water storage, saturated hydraulic conductivity, soil cone penetration resistance, bulk density, water use efficiency and yield of corn (*Zeamays* L.) was investigated in a field experiment in a sandy soil in Mu Us Sandy Land of China in 2012–2014. Treatments includes four rates of soft rock to sandy soil in volume (0:1, 1:1, 1:2 and 1:5) were applied only in the first year. Adding soft rock amendments increased soil moisture, soil water storage and water hold water holding capacity; decreased soil saturated hydraulic conductivity, soil cone penetration resistance and bulk density. All soft rock amendments significantly ($P < 0.05$) increased grain yield and above-ground biomass, and improved water use efficiency in all three years. Grain yield increases ranged from 67.8% to 160.1%, above-ground biomass increases ranged from 54.0% to 143.3%, and water use efficiency increases ranged from 11.3% to 46.6%. The treatment with rate of 1:1 (soft rock to sandy soil in volume) had the greatest effect on soil physical properties averaged over the three years. The treatment with rate of 1:2 had the greatest effect on crop performance averaged over the three years. Soft rock amendments showed promise for improving soil hydraulic parameters and crop yield in Mu Us Sandy Land, and deserve further research.

1. Introduction

Desertification is one of the most critical types of land degradation and is being widely recognized as a serious threat to arid and semiarid environments worldwide (Veron et al., 2006; Li et al., 2018). Mu Us Sandy Land (also called Mu Us Desert) is one of China's four major sandy land with the area of 3.98×10^6 ha (Han et al., 2012), which is located in southeastern Ordos region in Inner Mongolia and northern Shaanxi Loess Plateau. Due to the long time grazing, unreasonable land reclamation for agriculture (Liu et al., 2010), fuel wood collection and fossil fuel exploitation, land desertification and low productivity were taken place in the Mu Us region (Liu et al., 2014; Han et al., 2015). The region is mainly a sandy agro-pastoral land embedded with desert patches. Nevertheless, drought and lack of water resource are the main limiting factors in agriculture production in this region. Therefore, improving the ability of soil to store water from limited precipitation, reducing evapotranspiration, and increasing water use efficiency, are essential strategies for sustainable development of rainfed agriculture.

In this region, there is an area of more than 1.67×10^6 ha covered by a kind of special soft rocks (also called Pisha sandstone or Feldspathic Sandstone) (Ni et al., 2008). The soft rocks composed of mudstone, thick layer sandstone and arenaceous shale (Bazhenov et al., 1993; Martin et al., 1999), which is a kind of loosely bound sedimentary rock formed during the Permian (approximately 250 million years ago), Mesozoic Triassic, Jurassic and Cretaceous period (Zhang et al., 2009). It is normally associated with sand and widely distributes in the Mu Us Sandy Land. The history of soft rock with low pressure conditions, which is due to the small thickness of overburden rock, results in a low degree of diagenesis, a low degree of sand cementation and poor structural strength (Wang et al., 2009).

Sandy land soil with little or no structure is highly permeable under both wet and dry conditions and it retains little or no water (She et al., 2014). However, soft rock had high content of silt and clay with high water retention capacity. Soft rock is also highly subject to weathering and rapidly expands when it comes into contact with water (Miščević and Vlastelica, 2014). Considering that the properties of soft rock was complementary with that of sand although their properties were obviously different, some research have found that soft rocks mixed into sandy soils can significantly decrease the water infiltration rate and water loss through evaporation of the soil, whereas enhancing the

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saturated water content and residual water content (Wang et al., 2013; Zhen et al., 2016). Thus, the soft rock was used as soil amendments for sandy soil in the Mu Us Sandy Land. The compound soil prepared by soft rock with sand supports a beneficial environment for crops growth (Zhu et al., 2017).More than 1600 ha new cultivated lands have been created by mixing soft rock into sandy soils in this region (Han et al., 2012). This showed that it is an effective ways to remediate sandy soil with incorporating soft rock.

However, the ratios of soft rock to sand for the compound soil had a significant influence on the crop growth, considering that various ratios of soft rock to sand played a crucial role in the soil physical and chemical properties, water retention, water conductivity (Chai et al., 2013; Fu et al., 2013). Also the suitable ratio of soft rock to sand could be different for various crops, owing to their different demand for soil properties. However, reports of soft rock used in agriculture are relatively few, and information about the quantitative effects of soft rock addition in sandy soil on crop yield in the compound soil is still inadequate in this region. The objective of this study was to evaluate the effect of different rates of soft rock amendments on spatial and temporal distribution of soil hydraulic properties including soil moisture, soil water storage, soil saturated hydraulic conductivity and water use efficiency, and crop above-ground biomass and grain yield in Mu Us Sandy Land.

2. Materials and methods

2.1. Experimental site and design

The experimental field is located in Dahanji village (38°27′53″N, 109°28′58″E) of Yuyang district, Yulin city, Mu Us Sandy Land of China. The location is in northern Shaanxi, with an altitude of 1210 m and a typical warm temperate monsoon climate. The mean annual temperature (1990–2014) is 8.1 °C, annual sunshine is 2879 h, annual total radiation is 145.2 kcal cm^{-2}, frost-free period is 150 d each year, annual precipitation is 414 mm (65% of which occurs from June to September). It represents the climate characteristics of a warm moist summer and a cool dry winter with annual precipitation of 300–500 mm and annual cumulative temperature (> 10 °C) of 2200–3400 °C in most of Mu Us Sandy Land (Han et al., 2015).

Long-term average climate data and daily mean temperature data were obtained from the weather bureau in Yulin, which about 5 km far away from the experimental field. Daily precipitation data were measured with rain gauge installed in the experimental field during the growing season. The precipitation during the growing season from early May to the end of September was 456.3, 552.4 and 290.3 mm in 2012, 2013 and 2014, respectively (Fig. 1).

The field experiment was conducted from 2012 to 2014, inclusive. The experimental design consisted of four ratios of soft rock to sandy soil in volume: 0:1 (CK), 1:1 (T1), 1:2 (T2) and 1:5 (T3) at 0–30 depth. This experiment was a randomized complete block factorial design with three replications. Each plot was 10 m wide by 12 m long, with a 2 m buffer zone between the plots. The diameter less than about 5 cm of soft rock was selected and applied in the treatments, and larger particles were crushed by machine. The soft rock was applied only one time in the middle of March 2012 for all treatments; air-dried fine sandy soil samples were thoroughly mixed with soft rock to obtain three different contents of soft rock. The surface was covered with a 30 cm deep compound soil with different ratios of soft rock to sand in each plot. Below 30 cm was local sand and the soil of 30–100 cm profile was homogeneous (Wang et al., 2013).

2.2. Experimental protocol

Aeolian sandy soil and soft rock are the two typical soils in Mu Us Sandy Land (Chen and Wang, 2012). Aeolian sandy soil is a frigid, Typic Haplustoll with sandy loam texture that has been formed from aeolian deposits. Soft rock is a type of loose rock that is specifically identified as an interbedded sandstone composed of thick layers of sandstone, sandy shale and shale that formed from fluvial clastic deposits and shales developed in the Jurassic, Triassic and Cretaceous periods (Miščević and Vlastelica, 2017; Vlastelica et al., 2016; Zhen et al., 2016), it is composed of quartz (70.5 ± 1.0%), feldspar (16.4 ± 0.5%), muscovite (12.9 ± 1.1%) and hematite (0.2 ± 0.05%). The properties of the aeolian sandy soil and soft rock are shown in Table 1.

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 (2012–2014). 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^{-1}. The Xian Yu335 was widely used in local corn production with moderate sensitive to water deficit (Zhang et al., 2012; Zhang et al., 2014). Compound fertilizer (90 kg N ha^{-1}, 40 kg P ha^{-1}, and 75 kg K ha^{-1}) 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^{-1} 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.

2.3. Field and laboratory measurements

Soil samples for gravimetric soil moisture content were obtained manually at three random positions in each plot with a soil auger, at depths of 0–10, 10–20, 20–40, 40–60, 60–80 and 80–100 cm at 1 d before sowing and 10, 30, 50, 70, 90, 110 and 130 d after sowing. The samples from each plot at same depth were mixed and the composite samples were packed in aluminum boxes and oven-dried at 105 °C until constant weight.

Soil water holding capacity and saturated hydraulic conductivity was measured at harvest time in each year with the gravimetric method (Mohamed et al., 2016) and the constant-head method (Reynolds, 2006), respectively. Undisturbed soil samples were collected from each plot from three random positions with a 10 cm diameter by 5 cm high cutting ring, at 0–10, 10–20, 20–30 and 30–40 cm depths. For water holding capacity, soil samples were saturated with deionized water and the top was covered by a plastic wrap to prevent the loss of water by evaporation. The samples were drained for 48 h at room temperature (Dugan et al., 2010; Koide et al., 2014). Then samples were taken after 48 h, weighed, oven dried at 105 °C until constant weight and reweighed. Water holding capacity was determined by the difference between the mass of the wet and dry sample. For soil saturated hydraulic conductivity, a perforated bottom was placed underneath the cutting ring to stabilize the soil, and a second 5 cm high ring was placed on top of the cutting ring and sealed with tape to prevent water leakage. The cutting rings were placed over a beaker. Water was added in the upper ring and kept at 5 cm head using the height of the upper ring as a guide. Leachate was periodically measured by dumping the beaker into a graduated cylinder. Soil saturated hydraulic conductivity was determined by the flow rate for steady state conditions.

Soil bulk density and cone penetration resistance was measured at 1 d before sowing in each year. For bulk density, a pit was excavated with horizontal ledges at depths of 0–10, 10–20, 20–30 and 40 cm. A 5 cm diameter by 5 cm high cutting ring was inserted vertically into each ledge and soil samples for bulk density measurements were removed. Soil samples were oven-dried at 105 °C until constant weight. Soil cone penetration resistance was measured by soil cone penetrometer TSJD-750 (Zhejiang Top Instrument Co., Ltd., Hangzhou, Zhejiang, China) at depths of 10, 20, 30 and 40 cm.

A 10 m^2 area of each plot was harvested by hand at maturity.to measure corn grain yield and above-ground biomass in each year.