Effect of Soft Rock Amendment on Soil Cone Penetration Resistance and Bulk Density in Mu Us Sandy Land

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Abstract. Effect of soft rock as soil amendment on soil cone penetration resistance and bulk density 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 decreased soil cone penetration resistance and bulk density. The treatment with rate of 1:1 (soft rock to sandy soil in volume) had the greatest effect on soil cone penetration resistance and bulk density averaged over the three years.

1. Introduction
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. 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 saturated water content and residual water content (Wang et al., 2013; Zhen et al., 2016). 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 soil cone penetration resistance and bulk density 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 cone penetration resistance and bulk density in Mu Us Sandy Land.
2. Materials and methods

2.1 Experimental site and design
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.

2.2 Field and laboratory measurements
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.

2.3 Data analysis
An analysis of variance (ANOVA) was performed using SAS Ver. 9.0 software (SAS Institute Inc., Cary, NC, USA). Tests of significant use the least significant difference (LSD) at $P \leq 0.05$. Mean values were reported in the tables and figures.

3. Results and discussion
Soil bulk density increased with depth at all treatments in 2012, 2013 and 2014 (Fig. 1). There was similar trend and the effect was significant at the 0-10, 10-20 and 20-30 cm, but not at the 30-40 cm layer in the three years. All soft rock treatments reduced soil bulk density, compared to the control, and the T1 treatment was always the lowest among the four treatments in the three years.

Soil cone penetration resistance increased with depth at all treatments (Fig. 2). In 2012, soil amendments had a highly significant effect ($P < 0.001$) in 20 cm soil layer, and there was no significant effect ($P > 0.05$) in any of the other soil layers. In 2013 and 2014, there was similar trend and the effect was significant at the 10, 20 and 30 cm, but not at the 40 cm layer. All soft rock treatments reduced soil cone penetration resistance, compared to the control, and the T1 treatment was always the lowest among the four treatments in 2012, 2013 and 2014.

![Figure 1. Vertical variation of soil bulk density with soil amendments in 2012, 2013 and 2014. Treatment code: CK, no soft rock control; T1, soft rock to sandy soil in volume 1:1; T2, 1:2; T3, 1:5. *, **, *** significant at 0.05, 0.01 and 0.001 probability levels. NS means not significant.](image-url)
Figure 2. Vertical variation of soil cone penetration resistance with soil amendments in 2012, 2013 and 2014. Treatment code: CK, no soft rock control; T1, soft rock to sandy soil in volume 1:1; T2, 1:2; T3, 1:5. *, **, *** significant at 0.05, 0.01 and 0.001 probability levels. NS means not significant.

Soil bulk density and soil cone penetration resistance were known to be highly correlated with soil physical properties, such as soil texture and structure (Celik et al., 2010; Vaz et al., 2011), which affects the ability of the crop root to penetrate soil to reach and absorb water and nutrients in the soil (Oussible et al., 1992; Mohammadshirazi et al., 2017). In this study, soft rock also had significant reduction effect ($P < 0.05$) on soil bulk density and soil cone penetration resistance in our experiment (Fig. 1 and Fig. 2). This was consistent with Hussien et al. (2012) and Xu et al. (2015) who reported reduced soil bulk density and soil cone penetration resistance with soil amendment. In 2012, the first year of this study, soft rock showed only a small effect in the deeper layer which may due to incorporation into the soil only in the surface layers by cultivation. The soft rock effect in 30-40 cm (the deeper layer) became evident in later years which may be due to deeper mixing of the soft rock by annual tillage of the soil at a nominal depth of 30 cm. Soil compaction is usually characterized by soil bulk density and soil cone penetration resistance and is related to the structural characteristics and functions (Håkansson and Lipiec, 2000).

4. Conclusions
Soft rock as a soil amendment decreased bulk density and soil cone penetration resistance, especially in 0-30 cm soil layers. This study showed the potential of soft rock as amendment on improving soil water properties in Mu Us Sandy Land. The mechanism of soil properties and yield have increased up to a certain level of soft rock application rate to the sandy soil is complex.

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