Effect of Soft Rock Amendment on Crop Performance in Mu Us Sandy Land

Zenghui Sun\textsuperscript{a, b, c}

\textsuperscript{a}Shaanxi Provincial Land Engineering Construction Group Co., Ltd, Xi'an, 710075, China
\textsuperscript{b}Shaanxi Key Laboratory of Land Consolidation, Xi'an, 710075, China
\textsuperscript{c}Key Laboratory of Degraded and Unused Land Consolidation Engineering, Ministry of Land and Resources of China, Xi'an, 710075, China
Email: sunzenghui061@126.com

Abstract. Effect of soft rock as soil amendment on water use efficiency and yield of corn \textit{(Zea mays 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. All soft rock amendments significantly \textit{(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 1:2 had the greatest effect on crop performance averaged over the three years. Soft rock amendments showed promise for improving crop yield in Mu Us Sandy Land.

1. Introduction
Mu Us Sandy Land (also called Mu Us Desert) is one of China’s four major sandy land with the area of $3.98 \times 10^6$ ha (Han et al., 2012), which is located in southeastern Ordos region in Inner Mongolia and northern Shaanxi Loess Plateau. 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 $1.67 \times 10^6$ ha covered by a kind of special soft rocks (also called Pisha sandstone or Feldspathic Sandstone) (Ni et al., 2008). 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). 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). Thus, the soft rock was used as soil amendments for sandy soil in the Mu Us Sandy Land. 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 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 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 cm 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
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. 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. A 10 m² area of each plot was harvested by hand at maturity to measure corn grain yield and above-ground biomass in each year.

2.4. Data analysis
Evapotranspiration was determined using the soil water balance Eq. (1) (Allen et al., 1998):

\[
ET = \Delta SW + I + P - R - D + CR
\]  

where ET is evapotranspiration (mm), \(\Delta SW\) is the change of water storage in 0-100 cm soil profile during the growing season (mm), I is water added by irrigation (mm), P is the total precipitation during the growing season (mm), R is surface runoff (mm), D is deep drainage (mm), CR is capillary rise (mm). The experimental field was flat (no runoff occurred, \(R = 0\)) and the groundwater table was deep (no water was added by capillary action, \(CR = 0\)). When soil SW in the 0-100 cm soil profile was so high that additional precipitation made it above the field capacity (FC), it was assumed that excess water percolated into the deeper zones. The equation for drainage is as Eq. (2):

\[
D = \begin{cases} 
0 & \text{SW} + P \leq FC \\
SW + P - FC & \text{SW} + P > FC 
\end{cases}
\]  

Water use efficiency (WUE) was calculated as Eq. (3):

\[
WUE = \frac{Y}{ET}
\]
where WUE is the water use efficiency (kg ha\(^{-1}\) mm\(^{-1}\)), Y is corn grain yield (kg ha\(^{-1}\)), and ET is actual evapotranspiration (mm).

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

3.1. Grain yield and above-ground biomass

The corn yield for all soil amendment treatments was significantly greater \((P < 0.05)\) than that for CK for all three years (Fig. 1a). Amendment treatments increased 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 CK treatment; the T2 treatment had the highest corn yield with 6203.58, 8547.26 and 5218.76 kg ha\(^{-1}\) in 2012, 2013 and 2014 respectively.

Similar with the corn yield, the above-ground biomass for T1, T2 and T3 treatments was significantly greater \((P < 0.05)\) than that for CK for all three years (Fig. 1b). Amendment treatments increased the above-ground biomass by 58.8-83.3\%, 54.0-68.7\% and 101.4-143.3\% in 2012, 2013 and 2014 over that for CK treatment respectively. The T2 treatment had the highest above-ground biomass with 12543.32, 15327.45 and 11023.58 kg ha\(^{-1}\) in 2012, 2013 and 2014 respectively.

3.2. Water use efficiency

The soil amendment treatments significantly \((P < 0.05)\) improved WUE in our experiment with conditions of limited precipitation (Fig. 2). The T2 treatment had the highest WUE with 24.23, 24.12 and 21.35 kg ha\(^{-1}\) mm\(^{-1}\) in 2012, 2013 and 2014 respectively. Amendment treatments increased the WUE by 12.2-49.1\%, 11.3-38.5\% and 16.0-46.6\% in 2012, 2013 and 2014 over that for CK treatment

![Figure 1](image-url)
respectively. In 2014 which was a very dry year, the percentage improvements in WUE by soft rock amendments were greater than those in other years. Thus, under the drought conditions, the amendment effect on WUE was greater.

![Figure 2](image.png)

**Figure 2.** Water use efficiency 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. Columns within the same year and with the same letters are not significantly different at $P < 0.05$ according to a protected LSD test.

4. Discussion

This study showed that soft rock significantly ($P < 0.05$) increased corn yield, above-ground biomass and WUE (Fig. 1 and Fig. 2). This was consistent with other researches (Dorraji et al., 2015; Xu et al., 2015; Mi et al., 2017) that showed synthetic or natural soil amendments both significantly increased crop yield and above-ground biomass under different irrigation levels in sandy soils in semi-arid regions. However, the effects of amendments on crop growth and yield are often contrasting same soil and environment conditions in few studies. In wheat grown in sandy loam with 0.3% amendment of hydrogel, Akhter et al. (2004) showed increased wheat growth whereas Geesing and Schmidhalter (2004) reported no growth effect. 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 T1, T2 and T3 treatments increased total three years grain yield by 3146, 3471 and 2840 kg ha$^{-1}$. The T2 treatment was optimum in the three years. The difference in above-ground biomass and grain yield among treatment in this experiment was higher in 2014, which was due to lower rainfall. This contributed to increased plant water uptake and enhanced crop performance. Under limited rainfall, the soft rock held the water which reduced loss by evaporation, and consequently, WUE was strongly related to crop yield in relatively dry years such as in 2014. In contrast, 2013 with plentiful rainfall, the soft rock had a smaller effect on WUE. This approach could potentially be used not only to reduce soil erosion but also to increase the use of sandy land areas for agricultural production. Application of soft rock 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 Land.

5. Conclusions

Soft rock significantly ($P < 0.05$) increased corn yield, above-ground biomass and water use efficiency, the treatment with rate of 1:2 (soft rock to sandy soil in volume) was the best. This study showed the potential of soft rock as amendment on improving soil water properties and corn yield 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. The further research into the long-term effect of soft rock on soil chemical, biological properties and soil microbial community structure is required to gain a better understanding of the mechanism of soft rock as amendment for increasing crop yield in Mu Us Sandy Land, China.

6. Acknowledgments
This work was supported by the Fundamental Research Funds for the Central University of Changan University (300102278502) and the Scientific Research Item of Shaanxi Provincial Land Engineering Construction Group (DJNY2018-23).

7. References
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