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THE REMEDIATION METHOD OF SANDY LAND IN THE FELDSPATHIC SANDSTONE AREA - A REVIEW

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Abstract. This review presented a remediated technology that sand was remediated by feldspathic sandstone to convert to usable land and synthesized formation mechanism of remediated soil (sand remediated by feldspathic sandstone), highlighting the effect of remediated soil on the agriculture as well as pointing out the effect of sand stabilization of remediated soil. This paper could be helpful to guide the remediation method on sandy land where feldspathic sandstone was associated with sand and widely distributed, such as Mu Us feldspathic sandstone area, as well as to suggest useful avenues to improve the physical and chemical properties of the sandy land which was favorable for sustainable crops growth. Sand remediated by feldspathic sandstone, could be fixed, and soil erosion could be effectively prevented as well as its surrounded ecological environment could be well protected. This research has important theoretical and practical significance in the feldspathic sandstone area, for the sand remediated by feldspathic sandstone is proved to be a sustainable way to comprehensively improve the sandy land, and to solve soil erosion problem in feldspathic sandstone areas with remarkable economic, social and ecological efficiency.

Keywords: Feldspathic sandstone, Sandy land, Remediation, Sand stabilization, Sustainability

1. INTRODUCTION

Feldspathic sandstone is composed of thick layer sandstone, arenaceous shale and mudstone (Bazhenov et al., 1993; Martin et al., 1999), and is a kind of loosely bound sedimentary rock formed during the Permian, Mesozoic Triassic, Jurassic and Cretaceous period (Zhang et al., 2009a). It is normally associated with sand and widely distributed in the Mu Us Sandy Land, one of China's four major sandy lands and located at southeastern Ordos Plateau and north of northern Shaanxi Loess Plateau (Zhang et al., 2009b). Serious land degradation and desertification have been produced in this region due to the unreasonable land reclamation and overgrazing (Liu et al., 2010; Yan et al., 2013). Considering the fact that feldspathic sandstone is extremely hard when it is dry but very soft and frail under wet condition (Zhang et al., 2009b), it is readily being eroded by wind and water, which lead to the soil erosion, and pose a serious threat for sustainable agriculture and environment. As a consequence, its threat to vegetation and environment is often compared to the toxin of arsenic as a metaphor and thus it is also conventionally called as Pisha sandstone (Chinese Pinyin of arsenic, Yang et al., 2014).

Frequent sandstorm disasters caused by desertification and serious soil and water loss generated by sand and feldspathic sandstone not only deteriorates the local ecological environment, but also seriously affects the economic and social development (Liu et al., 2014). Therefore, it is of great importance to remediate feldspathic sandstone area in order to control the wind sand hazards and stabilize sand, contributing to soil improvement and ecology restoration of this area.

Currently, methods have been developed or are now being developed which can remediate sandy land in effective or economic manner, including remediation of sandy land with clay (Kanayama et al., 2009), loess (Wang & Xiao-Xu 2009) and bentonite (Tripathi & Viswanadham 2012), etc. Research found that corn and sunflower could be planted in the sandy land remediated by saline-alkali soil (Zhou et al., 2011). Soybean and millet could grow in remediated soil with suitable ratio of sand to coal gangue (Zhang & Zhang 2010). Sandy land remediated by peat could be used to grow cabbages (Chen et al., 2003). Meantime, different kinds of vegetation were used to control soil erosion in feldspathic sandstone area (Cao et al., 2008; Cao et al., 2007). For example, sea buckthorn could be used to remediate feldspathic sandstone to control soil erosion in the Losses Plateau area (Yang et al., 2014; Zhang et al., 2009b). These studies, however, have not resolved the sandstorm problems and soil erosion simultaneously nor optimized the use of the resources in the feldspathic sandstone areas.

Feldspathic sandstone had enrichment of silt and clay grains with fair water retention capacity, but was vulnerable to weathering and soil erosion (Ibbeken & Schleyer 1991). However, sand was uniform or poorly graded and loosely bounded with high permeability but with poor water retention capacity. Desertification generated in sandy land and soil erosion caused by feldspathic sandstone was the reason for severe scarcity of soil and water resources, which caused the farmland reduction accordingly (Wang et al., 2013). Considering that the properties of feldspathic sandstone was complementary with that of sand although their properties were obviously different, feldspathic sandstone was used to remediate sandy land to form a remediated soil (Han et al., 2015), which could break the hard and compacted structure of feldspathic sandstone, as well as amend loose and porous sand, in order to enhance water productivity and arability of sandy land, contributing to the control of the soil erosion. Furthermore, the strong cementation between remediated soil grains could facilitate to form physical soil crust and to stable sand. In addition, the fair water retention capacity of remediated soil could benefit forming thick frozen soil layer, which played an essential role on the control of wind erosion and the improvement of sand fixation (Han et al., 2015).

For this reason, some literature have been published in recent years studying the methods of remediation of sandy land with feldspathic sandstone (Han et al., 2015; Han et al., 2012a; Han & Zhang 2014; Wang et al., 2014), but their extent has been limited, and specific to an individual study. There is no comprehensive review of this subject as far as we know. The intent of this review is to fill this gap. This review could potentially be used to establish a theoretical and empirical basis for sandy land remediation by feldspathic sandstone.

2. BACKGROUND ON FELDSPATHIC SANDSTONE

Feldspathic sandstone was a common sedimentary rock, intermediate in composition between arkosic sandstone and quartz sandstone, containing 10% to 30% feldspar and less than 30% matrix material of clay (e.g. kaolinite, calcium montmorillonite, and illite, Land et al., 1987). Quartz was usually the dominant mineral, and some sericite and calcite was often present (Nespereira et al., 2006).Feldspathic sandstone may be strongly cross-bedded and normally associated with coarse granite-bearing conglomerate (Crook 1960). Feldspathic sandstone grains were usually angular and poorly sorted (mixed randomly in differing sizes, Dey et al., 2008).

Feldspathic sandstone could be divided into purplish red, grey white and reddish grey in color, and their mineral composition and properties were different (Yuanchang et al., 2007). It was found that the water retaining capacity of purplish red feldspathic sandstone was better than that of grey white one, hence the purplish red one could hold more water than the grey white one (Shi et al., 2004). The purplish red feldspathic sandstone may be a potential material to remediate sand soil on account of its properties, e.g., high clay content, excellent water retaining capacity.

In northwest China, an area of more than 11000km^2 is covered by feldspathic sandstone (Fugui et al., 2002), and this area was plagued with a high erosion rate (over 20000t/km^{2}yr, Zhang et al., 2009b). The soil erosion problem generally resulted in poor vegetation condition in this area (Zhao et al., 2013).The soil erosion hazard was often intensified by the weathering of the bare feldspathic sandstone, leading to loose surface soil and the loss of fine particles, resulting in the loss of nutrient in soil eventually (Fang et al., 2012). Research reported that the annual eroded thickness of purplish red feldspathic sandstone and grey white one in valleys was 35mm and 14mm respectively (Shi et al., 1999), as a result, soil resource and ecological environment was deteriorated by the poor vegetation cover due to the increased eroded thickness and poor water retention capacity of sandy soil in feldspathic sandstone area.

Large amount of sediment derived from feldspathic sandstone area, discharging into large rivers and possibly depositing in the reservoir was very severe, and eventually harmed dams and reservoirs. It was found that feldspathic sandstone was a major source of coarse sediment for Yellow River and could produce considerable sediment (0.214 billion tons per year), accounting for 71.1% of the total coarse sediment yield (0.301 billion tons per year) in the middle reaches of Yellow River (JianHua et al., 2007). Also, the transportation of sediment to water bodies was accompanied by loss of nutrients, which lead to farmland infertile (Vanacker et al., 2003).

3. FELDSPATHIC SANDSTONE AND SAND PROPERTIES

3.1. Feldspathic sandstone properties

3.1.1. Feldspathic sandstone physical properties

Feldspathic sandstone was usually fine grained and its grading sizes were widely distributed, with about 72.9% of silt-sized (0.002-0.05mm diameter) and 7.5% of clay-sized (<0.002 mm) and 19.6% of sand-sized (0.05-2mm) grains (Chai et al., 2013).

Uniformity coefficients (Cu) and curvature coefficients (Cc) are often used in analysis of soil structure in order to study the mechanical behavior of soil (Chowdhury et al. 2001). Cu is a ration of d(0.6) by d(0.1), i.e., Cu =d(0.6)/ d(0.1), and Cc is equal to dividing the d(0.3) square by d(0.6) into d(0.1), i.e., Cc=(d(0.3)×d(0.3))/(d(0.6)×d(0.1)), where d(0.6), d(0.1) and d(0.3) is the particle size diameter for which 60 percent, 10 percent and 30 percent of the samples are finer respectively (Sánchez-Leal 2007). The higher of the Cu, the larger range of the particle size in the soil, which indicates the soil mass was consists of different ranges of the particle size (Omoregie & Alutu 2006). A soil having a Cu smaller than 5 is considered poorly graded, i.e., uniform. Uniform signify that the soils have identical size of the particles. For the soil to be well graded, the value of Cu has to be greater than 5, and Cc should be in the range of 1to 3 (Chowdhury et al., 2001). Therefore，Feldspathic sandstone was well graded soil, i.e., heterogeneous, and was well blender of the coarse and fine particle (Williams et al., 2010), because the Cu and Cc of feldspathic sandstone was 15.9 and 1.5 respectively (Table 1, Zhang et al., 2014a), and thus it was potential soil for crops growth.

Due to a lack of organic matter in the feldspathic sandstone or its poor structure, its structure was destroyed under the force of rainfall or irrigation, and the applied stress being internal suction due to water evaporation result in hardening of feldspathic sandstone.

Affected feldspathic sandstone was less able to absorb rainfall, thus increasing runoff and erosion. Crops had difficulty in compacted feldspathic sandstone because its mineral grains were pressed together, leaving little space for air and water, which were essential for root growth.

The bulk density of natural feldspathic sandstone was about 1.20 g/cm^3, and thus it values of porosity could be calculated as 54.72% according to its highest bulk density, i.e.,1.71g/cm^3. Thus its non-capillary porosity (i.e., aeration porosity (Juan et al., 2014) was only 9.88%, because its capillary porosity was 44.94% (Han et al., 2012a), which indicated that its ventilation and water permeability was far lower than the appropriate aeration porosity range of arable layer (i.e., 15-20%). Meantime, its high content of clay-size grains often resulted in the fact that clay blocked the surface pores after rainfall or irrigation, as a result, feldspathic sandstone could become like mud after rain (Luo & Wang 2015). Then soil compaction occurred readily in feldspathic sandstone after water evaporation, so feldspathic sandstone could be as hard as stone under dry condition (Han et al., 2012a). Besides, low organic matter content of feldspathic sandstone was also the reason for soil compaction. Poor organic matter could worsen soil structure and impact microbial activity, thus affecting the formation of soil aggregates, which spelled the shrink of the soil, causing it to crack. In addition, storm and sandstorm induced serious water loss and soil erosion, deteriorating soil structure, which also generated soil compaction.

3.1.2. Feldspathic sandstone chemical properties

As sandstone, feldspathic sandstone was not a kind of rock with high hardness, but rather was a soft rock, vulnerable to weathering erosion. Cementation of feldspathic sandstone caused by carbonate and clay mineral, and the main composition of carbonate were calcite and small amount of dolomite (Leng & Yao 2015). Chemical properties of calcite were very active, reacting with carbon dioxide in the water, forming soluble calcium hydrogencarbonate to destroy the structure of feldspathic sandstone (Vicente 1983). Also calcite had weak weathering resistance. The matrix of feldspathic sandstone was clay mineral, including montmorillonite and few illite and kaolinite with the hydrophilic and water swelling ability (Luo & Wang 2015).

Table 1. Structure properties of feldspathic sandstone, sand and remediated soil with different ratios

Parameter	Sand	Feldspathic sandstone	Ratios of feldspathic sandstone to sand		
			1:5	1:2	1:1
volume diameter(μm)	/	/	267	195	133
C_u	2.63	15.90	78.75	112.01	29.37
C_c	0.87	1.50	7,84	0.37	0.96
Water-stable macro-aggregates (%)	10.87	/	18.38	21.55	28.22

C_u (Uniformity coefficients), C_c (curvature coefficients)

The chemical composition of feldspathic sandstone showed enrichment (at least 85%) in stable composition, including SiO_2, $Al_2O_3$and FeO (Chai et al., 2013) and slight unstable composition, i.e., Na_2O, K_2O and CaO (Götze 1998), which were exceptionally active and apt to chemical changes, thus destroying rock. Feldspathic sandstone was hard when it is dry but rapidly expands under wet condition with excellent water retention ability and poor permeability (Yang et al., 2014).

3.2. Sand properties

3.2.1. Sand physical properties

Sand on the Mu Us sandy land was a raw, coarse-grained sandy soil with about 3.1% clay-size, 5.5% silt-size and 91.4% sand-sized grains (Chai et al., 2013). Consequently, its clay and silt content in sand was rare, and sand was extremely porous, and had no structure with poor anti-wind erosion capacity (Han & Zhang 2014).

C_u value of sand on the Mu Us sandy land was 2.63 (Table 1, Zhang et al., 2014a), indicating that the range of the sand particle size distribution was narrow, and hence the sand was considered poorly graded, i.e., homogeneous. Also its C_c value was 0.87, which showed that its size grading was not continuous (Zhang et al., 2014a). Therefore, it was not suitable for crops growth.

The bulk density of natural sand on the Mu Us sandy land was about 1.60 g/cm^3, and thus it total sand porosity could be calculated as 39.62% according to its highest bulk density, i.e., 1.73 g/cm^3. Thus its non-capillary porosity (i.e., aeration porosity) was only 13.29% because its capillary porosity was 26.33% (Han et al., 2012a), which showed that sand was highly permeable but retained little or no water. Considering its depletion of clay and silt particles and enrichment of sand particles, attraction between particles was lacked and loosely bound particles was apt to move, leading to wind erosion (Luo & Wang 2015).

3.2.2. Sand chemical properties

Quartz and feldspar were main mineral components in sand (Defu 2004). And the average content of organic matter, total nitrogen, total phosphorus and rapidly available potassium in aeolian sand was about 1-3g/kg, 0.03g/kg, 0.003g/kg, 0.09g/kg respectively (i.e., the nutrient of sand was low, Chai et al., 2013). The particle size of sand were large (Chai et al., 2013), and thus forces of molecule attraction were relative small, resulting in its low capillary porosity and high water permeability.

4. MECHANISM OF SAND REMEDIATED BY FELDSPATHIC SANDSTONE

4.1. Remediated soil properties

The remediated soil was prepared by mixing the feldspathic sandstone and sand at the ratio of 1:1, 1:2 and 1:5 and the influence of remediated soil at different ratio on the grain-size composition and distribution was study. With the increase of the proportion of feldspathic sandstone in the remediated soil, the volume diameter (Table 1) of remediated soil decreased from 267μm (1:5 ration of feldspathic sandstone to sand) to 133μm (1:1 ration of feldspathic sandstone to sand), which showed that feldspathic sandstone addition could decrease the remediated soil grain-size (Han et al., 2012b). Thus, the sand remediated by feldspathic sandstone could implement the grain-size refinement.

C_u value of remediated soil with different ratio was far larger than that of feldspathic sandstone and sand respectively (Table 1, Zhang et al., 2014a), which could be because that blender of the feldspathic sandstone and sand increased the soil particle size distribution range. Meantime, with the increased proportion of feldspathic sandstone in the remediated soil, the C_c value increased, indicating that its size grading become continuous (Zhang et al. 2014a).

Besides, with the increase of feldspathic sandstone in the remediated soil, the content of silt-sized and clay-sized grains increased gradually and the sand-sized grains decreased significantly and the soil texture changed from sand to silt loam (table 2, Luo & Wang 2015). Therefore, the sandy soil texture was improved by the addition of the feldspathic sandstone. Consequently, aeration which is essential for crops root growth was satisfied in the remediated soil and the water and fertilizer retention of remediated soil was enhanced, and its resistance to erosion was promoted.

As the most basic soil structural unit, soil aggregate has tremendous effects on soil physical and chemical properties, and could affect gas exchange between the soil and atmosphere and soil enzyme species and activity, also play an important role in plant productivity (Cambardella & Elliott 1992; Tisdall & Oades 1982). Soil aggregates could be divided into water-stable aggregates, mechanics-stable aggregates and biology-stable aggregates based on the difference of soil structural stability (Handayani et al., 2009). Water-stable aggregate is commonly used to evaluate the stability and anti-erosion ability of soil structure (Angers 1992).The aggregates whose size is larger than 0.25 mm are called macro-aggregates and are very important index to indicate soil structure (Tisdall & Oades 1980). And the content of water-stable macro-aggregates increased with the increased proportions of feldspathic sandstone in the remediated soils (Table 1, Han et al., 2012b), which showed that the remediated soil structure was improved by the increase of the content of feldspathic sandstone added in sand (Han et al. 2015). Therefore, the feldspathic sandstone could play a positive role in improving the remediated soil structure.

The properties of feldspathic sandstone and sand were complementary in remediated soil (Han et al., 2012a). For instance, compaction of feldspathic sandstone could be avoided by the dispersion of sand in the remediated soil, creating environment for the plant growth (Han et al., 2015). In the presence of sand, capillary porosity and permeability of feldspathic sandstone was enhanced. Sand porosity and capacity of water retention could be enhanced by the addition of the feldspathic sandstone, improving the capability of preserving soil, water and nutrient (Zhang et al., 2014b). Also the addition of sand could significantly decrease the clay-sized content of remediated soil, playing a role on reducing remediated soil compaction (Luo & Wang 2015).

4.2. Mechanism of remediated soil formation

The mechanism of remediated soil formation mainly included following aspects (Terzaghi 1959; Wu 1976).

1) Physical effect: due to the remediation of feldspathic sandstone in sand, the non-capillary porosity of sand was filled by feldspathic sandstone grains, hence sand capillary porosity was enhanced, and its permeability was reduced. Also sand particle was firmly attached and bound together under the effect of capillary pressure, thus forming soil aggregates.

2) Chemical effect: the feldspathic sandstone was rich in carbonate minerals, accordingly when feldspathic sandstone and sand was mixed in the remediated soil, sand and silt could be cemented to form aggregates under the force of cementation, caused by carbonate minerals, which could facilitates the formation of soil structure. The effect was intensive and stable with invulnerability.

3) Biological effects: biological activity in soil generated considerable impact on the forming of remediated soil, for instance, root extension and animal activity could promote the mixture of feldspathic sandstone with sand in remediated soil, contributing to forming favorable soil texture and structure. And animal manure and secretion of roots and microorganisms could raise the amount of soil organic matter, termed as soil cementing agent, which is conducive to the formation of granular structure. Also human activities could promote or disturb soil formation.

Overall, the mechanism of remediated soil formation mainly included capillary pressure generated by surface tension of unsaturated water in capillary pore, cementation force produced by carbonate minerals known as cement in feldspathic sandstone and effect of biological activities and its secretion as well as the influence of human activity.

5. EFFECT OF REMEDIATED SOIL ON THE CROPS GROWTH

The influence of sand remediated by feldspathic sandstone at different ratio on the soil property was study, also the soil water retention capacity was researched, to ensure that the sand remediated by feldspathic sandstone could be favorable for crops growth, thus finding out a proper ratio of feldspathic sandstone to sand in the remediated soil to achieve its best effect on preserving water and nutrient.

5.1. Remediated soil properties

The soil texture could be an important factor in affecting the soil permeability, and soil conservation of fertilizer and water. Research reported that with the increase of the content of feldspathic sandstone in the remediated soil, the content of sand-sized grains decreased, but the silt-sized grains increased (Table 2, Pei et al., 2013). Clay-sized grains increased by increasing the proportion of feldspathic sandstone to 50% in the remediated soil, but when the proportion of feldspathic sandstone were more than 50%, the clay-sized grains decreased with the increased of the proportion of feldspathic sandstone (Table 2, Han et al., 2012a). Zhang et al., (2014a) mix the feldspathic sandstone and sand at the ratio of 1:0, 5:1, 2:1, 1:1, 1:2, 1:5 and 0:1 to prepare remediated soil and study the influence of remediated soil at different ratio on the soil texture and grain size distribution. Research showed that the 1:5 ratio of the feldspathic sandstone to sand was the threshold that the soil texture changed from sand to sandy loam. And the soil texture was still silt loam when the ratio of feldspathic sandstone to sand was 2:1, even the proportion of the feldspathic sandstone kept increasing (Han et al., 2012b; Zhang et al., 2014a). Therefore, the best ratio of the feldspathic sandstone to sand in the remediated soil should be between the 1:5 and 2:1 according to the analysis of the soil texture. Meanwhile, the capillary porosity gradually increased as the proportion of feldspathic sandstone increased in the remediated soil (Table 2, Han et al., 2012b).

Soil organic matter content is commonly used to evaluate soil fertility (Yang et al., 2014), plays pivotal roles in several processes of the soil ecosystem, including nutrient cycling, soil structure formation, water retention, and energy supply to soil microorganisms (Wardle et al., 2004). Also crop yield could be related to soil organic matter, for it was found that significant relationships between crop yield and organic matter content could be obtained (Carter 2002).Therefore, the addition of organic matter content in the soil could contribute to crop growth, the increase of its yield and improvement of its quality (Olk et al., 2006). In addition, the soil organic matter would significantly affect the proportions and distributions of soil aggregates (Unger 1997), thus improving soil structure and enhancing its stability (Xinhua et al., 2004). The organic matter of the sandy soil could be improved by addition of feldspathic sandstone. The organic carbon contents changed from 0.053% to 0.106% when the ratio of the feldspathic sandstone to sand changed from 0:1 to 1:0 (table 2, Han et al., 2012b). Also the organic matter contents increased with the increase of planting years at remediated soil (Chai et al., 2013). It was reported that after 4 years plant growth, the organic carbon contents of remediated soil at the 1:5, 1:2 and 1:1 ratio of feldspathic sandstone to sand increased 12.25, 8.27 and 10.79 times, respectively. The organic matter contents of remediated soil were lower than normal organic matter contents in soil, but through the reasonable fertilizer and farming methods, the soil organic matter contents could increase (Han et al., 2012b). Therefore, the remediated soil with feldspathic sandstone and sand could have an effect of preserving fertilize.

In addition, the content of water-stable macro-aggregates increased with the increased content of feldspathic sandstone proportions in the remediated soils (Table 1, Chai et al., 2013), which showed that the sand structure was the least, and the remediated soil structure was improved by the increase of the content of feldspathic sandstone added in sand. Therefore, the feldspathic sandstone could play a positive role in improving the remediated soil structure.

5.2. Water retention capacity of remediated soil

The soil moisture is a significant index to evaluate soil quality for the lack of soil moisture is the biggest stumbling block for vegetation growth and insufficient moisture will cause earlier weakening of vegetation (Hagan 1955; Juan et al., 2014). Meantime, the water retention of soil, consistent with soil permeability, is used to evaluate water conservation (Manrique et al., 2008; Uhland 1951). The water retention valuated by soil moisture (Burden & Selim 1989), is a key prerequisite for plant growth, and could affect plant survival directly (Manrique et al., 2008). Field capacity and moisture content of the remediated soil was increased by the addition of the feldspathic sandstone (Table 3, Zhang et al., 2014b). Report suggested that the amount of available soil moisture in the remediated soil was maximum (i.e., 10.04%), and the water retaining performance was best when the ratio of feldspathic sandstone and sand was 5:1 (Table 3, Zhang et al., 2014a). As the capillary porosity of feldspathic sandstone was higher than that of sand, the field water holding capacity and the water retention was improved significantly in the remediated soil (She et al., 2014).

Soil water loss content and water loss rate is also the indicator for the soil water retention (Nielsen et al., 1973). Water loss rate is depended on the soil initial moisture content and soil water retention capacity (Merdun et al., 2008). And water loss content and water loss rate decreased with the increased content of feldspathic sandstone (Luo & Wang 2015), which indicated that water retention of feldspathic sandstone was better than that of sand. Feldspathic sandstone and sand were mixed to reduce the water loss in sandy soil and thus the water retention was increased (She et al., 2014).

Saturated hydraulic conductivity (Ks) describes water movement through saturated soil, and is an indicator to reflect the soil permeability (Kumar et al., 2008), i.e., with the increase of the saturated hydraulic conductivity, the soil permeability increase, and the water retention capacity decrease (Fares et al., 2000). It was reported that sand Ks value decreased as the proportion of the feldspathic sandstone increased in the remediated soil (Table 3, Han et al., 2012b).

Table 2. Properties of feldspathic sandstone, sand and remediated soil with different ratios

Parameter	Sand	Feldspathic sandstone	Ratios of feldspathic sandstone to sand				
			1:5	1:2	1:1	2:1	5:1
Clay size (%)	3.10	7.49	5.13	5.29	8.24	7.66	7.21
Sand size (%)	91.40	19.57	74.79	64.67	46.84	33.76	20.61
Silt size (%)	5.50	72.94	20.08	30.04	44.92	58.58	72.18.
Texture	Sandy soil	Silt loam	Sandy loam	Sandy loam	loam	Silt loam	Silt loam
Capillary porosity (%)	26.33	44.94	28.17	30.13	33.89	38.18	42.20
Organic matter (%)	0.053	0.106	0.043	0.048	0.042	0.077	0.105

Table 3. Water retention capacity of feldspathic sandstone, sand and remediated soil with different ratios

Parameter	Sand	Feldspathic sandstone	Ratio of feldspathic sandstone to sand				
			1:5	1:2	1:1	2:1	5:1
Field capacity (%)	5.99	23.46	9.80	13.13	15.68	19.65	21.54
Available soil moisture (%)	4.39	11.36	5.61	6.49	6.96	8.81	10.04
Ks(mm/min)	7.10	0.07	1.61	0.49	0.26	0.13	0.1

It had been documented Ks value decreased significantly as the proportion of feldspathic sandstone increased in the remediated soil (She et al., 2014). It indicated that the hydraulic conductivity of feldspathic sandstone was low for the fine-grain in feldspathic sandstone could block the pores for water exchange readily (Juan et al., 2014), leading to the poor drainage. Therefore, the permeability of sand could be reduced by the addition of the feldspathic sandstone to better the water retention in remediated soil. When the ratio of feldspathic sandstone to sandy land soil was 1:2, the Ks value was 0.49 mm/min, which was 14.5 times less than the sandy land soil (Pei et al., 2013). The Ks value continued to decline as the proportion of the feldspathic sandstone in the remediated soil increased. However the 1:2 ratio of the feldspathic sandstone to sand was a turning point that the decreased trend of saturated hydraulic conductivity flattens. It was concluded that when the mix ratio of feldspathic sandstone to sand were between 1:5 and 1:2, the remediated soil could conduct water in an appropriate range (Han et al., 2012a).

Besides, particle diameter and coverage of the feldspathic sandstone also played a role in affecting the water retention. The exposed feldspathic sandstone could absorb water effectively, and the feldspathic sandstone covered by sand could hold water effectively. And feldspathic sandstone with particle diameter between 2cm and 4cm could absorb and hold water more effectively than that of other diameter (Han et al., 2012b).

Water was absorbed and conserved by the feldspathic sandstone under sufficient water condition, and thus the water infiltration in remediated soil was reduced. On the other hand, water absorbed by the feldspathic sandstone could be released slowly into the environment under the force of osmotic pressure and matric potential when soil was drought.

Consequently moisture contents available for plant uptake in the remediated soil were increased, and water loss and evaporation was effectively prevented, and utilization efficiency of irrigation water or rainfall was increased.

5.3. Suitable ratio of feldspathic sandstone to sand for crops growth

The remediated soil prepared by mixing feldspathic sandstone with sand supported a beneficial environment for crops growth due to the melioration of soil properties and structure by the addition of the feldspathic sandstone. Diverse crops were planted in the remediated soil in good condition with substantial yield (Han et al., 2012b) e.g., corn, soybean, wheat, photo, rape, chives, garlic, spinach and cockscomb etc. Therefore, the remediated soil could support requirement of crops development. However, the ratio of feldspathic sandstone to sand of the remediated soil had a significant influence on the crops growth (Chai et al., 2013), considering that diverse ratio of feldspathic sandstone to sand played a crucial role in the soil physical and chemical properties, water retention, water conductivity, etc. Also the suitable ratio of feldspathic sandstone to sand could be different for diverse crop species (Pei et al., 2013), owing to their different demand for soil properties.

Researcher found that net photosynthetic rate, transpiration rate, stomatal conductance and chlorophyll content values of wheat flag leaf was the highest in the remediated soil at the 1:2 ratio of feldspathic sandstone to sand, compared with that of remediated soil at other ratio during different growth stage of wheat (i.e. heading stage, flowering stage and filling stage, Juan et al., 2014). This could be attributed to the high moisture content in remediated soil at the 1:2 ratio of feldspathic sandstone to sand for the reason that it is reported that high soil moisture content could result in strong photosynthesis of plant (Juan et al., 2014).

And the wheat biomass in the remediated soil at 1:2 ratio of feldspathic sandstone to sand was significantly higher than that of the remediated soil at other ratio. And the wheat yield in the remediated soil at the 1:2 ratio of feldspathic sandstone to sand was the highest (Han et al., 2012b; Juan et al., 2014). Therefore, it could be concluded that the remediated soil at the 1:2 ratio of feldspathic sandstone to sand was suitable for wheat growth, which could be because that the remediated soil at the 1:2 ratio of feldspathic sandstone to sand with favorable soil property (i.e., soil texture, capillary porosity, water retention and water permeability, etc.) for wheat seed germination, thus promoting its development.

Meantime, height at the ripening stage, thousand-grain weight, grain number per spike and yield of wheat, corn and soybean in the remediated soil at 1:2 ratio of feldspathic sandstone to sand was the highest compared with that at other ratio (Table 4, Juan et al., 2014). But the remediated soil at 1:5 ratio of feldspathic sandstone to sand was suitable for potato because the yield of potato in the remediated soil at 1:5 ratio of feldspathic sandstone to sand was the highest compared with that at other ratio (table 4, Han et al., 2012b; Pei et al., 2013). Consequently, the proper ratio of the remediated soil in which crops are cultivated could vary with diverse crop species, which should be considered in the actual application.

6. EFFECT OF REMEDIATED SOIL ON SAND STABILIZATION

6.1. Soil crust of remediated soil

Soil crusts are thin surface layer of dense soil that is different from the rest of the bulk soil. Physical soil crusts are commonly hardened with raindrop or clay dispersion impacts due to the accumulation of salts and silica (Feng et al., 2013). Soil crusts, characterized by an interlocking network of particles that reduce the susceptibility of the soil to erosion when exposed to wind (Zobeck 1991), generally could increase soil bulk density and soil compatibility, resulting in the increase of the soil surface stability (Xinrong et al., 2000). Researcher showed that the through mixing the feldspathic sandstone and sand, the formation of the physical soil crust could be promoted in the force of water and the ratio of the feldspathic sandstone to sand had a significant influence on the thickness of the physical soil crust (Luo & Wang 2015).

And the soil erosion study in Mu Us Sand land indicated that compared to uncrust sand land, soil crust contributed to reducing the wind erosion amount by 49%-68%. Therefore, the sand stabilization could be improved by mixing feldspathic sandstone with sand, which could be attributed to that physical soil crust, facilitated by the feldspathic sandstone, commonly prevented from wind erosion and could play an important role in fixing drifting sand.

6.2. Frozen soil layer of remediated soil

Frozen soil layer on the sand surface is structurally important and could stabilize sand, reducing its vulnerability to erosion by wind, and its thawing has been known to cause wind erosion (Wang et al., 2005). The high content of remediated soil moisture, as a result of strong water retention of feldspathic sandstone (Han et al., 2012a), provided a favorable environment for the formation of the frozen soil layer on the remediated soil surface, which could better the soil surface stability and anti-wind erosion capacity. Meantime, soil moisture content affected the depth of the frozen soil layer (Funakawa et al., 2004). Therefore, the depth of the frozen remediated soil layer was higher than that of the sand due to the existence of the feldspathic sandstone in the remediated soil (Han et al., 2015). Considering that soil moisture could be increased by irrigation during the crops cultivation (Li et al., 2007), the depth of frozen remediated soil layer with crops cultivation was higher than that without cultivation (Luo & Wang 2015). In addition, it was discovered that the snow coverage and frozen soil layer on the remediated soil was thicker than that of original sand (Luo & Wang 2015), and the melting speed of snow coverage and frozen soil layer in remediated soil remedied by the feldspathic sandstone was slower than that in the original landform sand after snowfall (Han et al., 2015), which could be because that a higher moisture content in the remediated soil, as a result of the poor water conductivity of feldspathic sandstone (Han et al., 2012a), compared to the that in original sand, was responsible for the slow thawing there, resulting in slower water percolation from the frozen layers and in slower water loss through evaporation (Funakawa et al., 2004).

Water molecules were connected together by a large quantity of hydrogen bond during the water freezing and extended out from the ice surface (Murphy 1970). Then a protective layer was bound by the force of hydrogen bonds on sandy soil surface to isolate direct contact between air flow and loose sand surface. Therefore, Protective layers on the remediated soil surface were formed by snow coverage and frozen soil layer, reducing the wind erosion impact.

Besides, soil freezing and thawing had a significant influence on soil structure, soil composition and physical, chemical and biological process in soil (Edwards & Cresser 1992). It was reported that the soil texture and its aggregates stability was affected by freezing and thawing process (Lehrsch et al., 1991; Mbagwu & Bazzoffi 1989).

Table 4. Effect of remediated soil with different ratio on the yield of corn, wheat, potato and soybean

Ratios of feldspathic sandstone to sand	Corn yield(t/hm^2)	Wheat yield(t/hm^2)	Potato yield(t/hm^2)	Soybean yield(t/hm^2)
1:1	7.5	6.3	25.11	2.88
1:2	8.75	8.21	29.25	4.60
1:5	8.25	6.41	35.24	3.96

Alternation of the soil freezing and thawing could effectively break the soil macro-aggregates into micro-aggregates and could increase the stability of soil aggregates on soil surface (Oztas & Fayetorbay 2003). Consequently, the remediation of feldspathic sandstone on sandy soil was conducive to increase the stability of soil aggregates, and could enhance the soil structure and effect on sand fixation due to the formation of the frozen soil layer on the remediated soil remedied by feldspathic sandstone.

6.3. Soil moisture of remediated soil

As a water retaining agent, feldspathic sandstone could remarkably decrease the loss of sandy soil moisture (Han et al., 2012a), thus increasing soil moisture content, which was known as a vital wind erosion resistance factor, owing to that deficiency of soil moisture was commonly associated with wind erosion (Chepil 1956). It was reported that moisture significantly increased threshold wind velocities for the initiation of sand movement. Since the process of surface sand grain divorced from surface under the wind force marked the beginning of surface wind erosion, sandy soil moisture posed an obvious inhibitory effect on wind erosion (Van Dijk et al., 1996). As a result of the water retention capacity of the feldspathic sandstone, moisture of remediated soil was significantly higher than that of sandy soil. Therefore, sandy land remediated by feldspathic sandstone could increase moisture content of soil surface layer in order to improve wind erosion resistance eventually (Han et al., 2015).

7. SUSTAINABLE UTILIZATION OF REMEDIATED SOIL

7.1. Sustainable utilization of remediated soil in agriculture

Through crop cultivation in remediated soil, the content of soil humus, known as the cement of soil structure, continuously increased, thus improving the remediated soil structure. Researcher found that the organic matter content of remediated soil at the 1:1,1:2 and 1:5 ratio of feldspathic sandstone to sand raised from 0.042 to 0.32%(1:1), from 0.048 to 0.13% (1:2) and from0.043 to 0.18 % (1:5) respectively after two year cultivation (Table 5, Chai et al., 2013).

In addition, soil water-stable aggregates contents increased after several years of cultivation. The water-stable macro-aggregates content of remediated soil at the 1:1,1:2 and 1:5 ratio of feldspathic sandstone to sand increased by 3.9%, 11.0% and 13.3% respectively after two year cultivation (Table 5, Chai et al., 2013). Remediated soil was sandy loamy soil, and its texture was improved and the arable layer increased with extension of cultivation year (Chai et al., 2013), which indicated that the remediated soil could be used in agriculture sustainably.

Through farming and fertilization, on one hand, the soil aggregates content increased, and thus the remediated soil become stable (Bronick & Lal 2005). On the other hand, the content of soil organic matter, considered as the organic cement for the formation of soil aggregate structure, increased, thus improving the soil structure (Gregorich et al., 1996; He et al., 2015). Besides, crops root exudates and decomposed products of crops stem and leaves could increase soil organic matter, improving the soil fertility (Nardi et al., 2000). Furthermore, with the enrichment of plant roots and microorganism in remediated soil through cultivation (Dick 1992), benthic organism e.g. worms would gradually increase, as well as its secretions and excrement, which could improve soil fertility and soil structure, promoting the maturation and development of the soil (Baker et al., 2006).

7.2. SUSTAINABLE UTILIZATION OF REMEDIATED SOIL IN SAND FIXATION

Sand stabilization by feldspathic sandstone is a solution to prevent sand and dust storm, which now are regarded as an environment problem (Han & Zhang 2014). Compared to other sand stabilizing method, it is simply performed with low cost, which could be attributed to the fact that feldspathic sandstone is normally associated with sand (Yang et al., 2014), and thus transportation cost is commonly saved. Also, the effect of fixing sand is obvious with quick efficiency due to the property of feldspathic sandstone and its complementation to sand (Han et al., 2012a). In addition, soil remediated by feldspathic sandstone could provide favorable environment for crops growth with suitable physical and chemical property (Han et al., 2012b), and thus resource utilization of sand could be achieved (Luo & Wang 2015).

Table 5. Sustainable utilization of remediated soil in agriculture

Ratios of feldspathic sandstone to sand	Organic matter (%)		Water-stable aggregates contents (%)	
	Before planting	Planting two seasons	Before planting	Planting two seasons
1:1	0.042	0.32	28.22	29.32
1:2	0.048	0.13	21.55	23.92
1:5	0.043	0.18	18.38	20.82

Besides, there is almost no second pollution of the sand stabilization by feldspathic sandstone, considering its heavy metal content being below the national standard (Luo & Wang 2015).The most importantly, this technology could be used in longtime to achieve the sustainable utilization and recycle of sand, which could be because through sand stabilization by feldspathic sandstone, physical and chemical properties of sandy land will gradually be improved though farming and fertilization (Chai et al., 2013).

8. CONCLUSION

This paper presented a remediated technology that sand was remediated by feldspathic sandstone to convert to usable land, and had reviewed this remediated soil formation mechanism and its effects on the sandy land reclamation and sand fixation.

Feldspathic sandstone areas, distributed in the Mu Us Sandy Land, have serious soil erosion and severe wind erosion, but feldspathic sandstone mixed with a certain percentage of sand was shown to increase land resource utilization. Through remediation of sand with feldspathic sandstone, the quality of the remediated soil was improved. Also the remediated soil has fair water and air permeability and water retention capacity, creating a suitable environment for crops growth. Meantime, the proper ratio of the remediated soil in which crops are cultivated could vary with diverse crop species. Furthermore, sandy land remediated by feldspathic sandstone could be used for a longtime with efficiency and effectives, which could be attributed that the remediated soil structure was further improved as well as soil fertility, and crop yields increased steadily through farming and fertilization.

Finally, the sand fixation effect was remarkable by the remediation of feldspathic sandstone, owing to the fact that physical soil crust and frozen soil layer were readily to be formed in remediated soil. The formation of a soil crust and the increased thickness of snow and the frozen layer in remediated soil all demonstrated that this remediated technology had a prominent sand fixation effect. As a result, this method could be applied in those areas where feldspathic sandstone was widely distributed to remediate sandy land, for the sand remediated by feldspathic sandstone was proved to be a sustainable way to comprehensively improve the sand land, and to solve soil erosion problems in feldspathic sandstone areas with remarkable economic, social and ecological efficiency. This research has important theoretical and practical significance in the Mu Us feldspathic sandstone area in terms of soil improvement and water loss control.

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