Desert soilization: The concept and practice of making deserts bloom

Zhijian Yi,1,* Min Wang,1 and Chaohua Zhao1

1The Desert Research Institute, Chongqing Jiaotong University, Chongqing 400074, China
*Correspondence: yizj63@hotmail.com
Received: November 24, 2021; Accepted: December 19, 2021; Published Online: December 23, 2021; https://doi.org/10.1016/j.xinn.2021.100200
© 2021 This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Citation: Yi Z., Wang M., and Zhao C. (2022). Desert soilization: The concept and practice of making deserts bloom. The Innovation 3(1), 100200.

Desertiﬁcation is a major global environmental problem. However, there still lacks effective means to control it.1 By using a technique called desert “soilization,”2 the surface layer of desert sand can be constrained together by mechanical means to form a new material with the mechanical states and water retaining capacity of soil, which is favorable for plant growth. Such a technique breaks through the conventional methods of desertiﬁcation control. Since the success of the ﬁrst soilization experiment in the Ulan Buh Desert in 2016,2 soilization has been successfully applied in different landforms and climates, shown in the map of Figure 1, including the Taklimakan Desert (Figure 1A), the Ulan Buh Desert (Figure 1B), desertiﬁed grassland (Figure 1C), the Middle East desert, the Sahara Desert, the Gobi desert, beach sand, and coral sand, with the total soilized area reaching 1,130 hm².

The desert soilization proposition is based on two scientiﬁc discoveries.2,3 One is that granular constraints determine the mechanical states of a granular material. The other is the relationship between the mechanical properties and the ecological attributes of soil. The desert soilization proposition is an outcome of interdisciplinary research integrating mechanics, materials, soil, biology, and ecology.

With the discovery that granular constraints determine the mechanical states of a granular material, sand is turned into “soil” by imposing an omni-directional integrative (ODI) constraint.3 Thus, the single discrete state of sand (Figure 1D) is converted into two mechanical states of soil, i.e., a rheological state when wet (wet soil, Figure 1E) and a solid state when dry (dry soil, Figure 1F). The imposition of the ODI constraint among sand granules is realized by mixing sand with a constraining material, which is a specially modiﬁed sodium carboxymethyl cellulose material.3 The constraining material becomes a cohesive solution after absorbing water. Then each sand granule is surrounded by a sticky coating of the solution, and the ODI constraint forms between any two granules in contact (Figure 1G). The formation of the ODI constraint is a physical process. Because the cohesive solution is retained among the sand granules, water in the solution is also retained with pores existing among the sand granules (Figure 1G). Therefore, the sand-turned “soil” exhibits strong capacity to retain water and nutrients (Figure 1E) as well as to aerate and grow microorganisms.

Figure 1. The desert “soilization” principle, effect, and places. The background is a soilized site in the Ulan Buh Desert in 2018. (A–C) The map shows the places where desert soilization has been applied, including (A) a soilized site in the Taklimakan Desert in 2018, (B) a soilized site in the Ulan Buh Desert in 2017, and (C) a soilized site in the desertiﬁed grassland in Zoige in 2018. (D–G) The mechanical principle of desert soilization. (H–I) The plant roots in the soilized sand. (J–K) Comparison of plant growth in the soilized and non-soilized sand in the Taklimakan Desert and the Ulan Buh Desert respectively. (L) The growth of heat-tolerant plants without artiﬁcial irrigation.
With the discovery of the relationship between the mechanical properties and ecological attributes of soil, the two eco-mechanical attributes of soil, i.e., self-repair and self-regulation, were disclosed. Self-repair implies that soil can repair its cracks or breakage in the solid state by returning to the rheological state after absorbing water. The self-repair attribute enables soil to maintain a perpetual eco-cycle. Self-regulation means any granular rearrangement does not affect the mechanical properties of the soil, and the soil continues to provide a relatively constant binding force to plant roots. Therefore, soil can regulate its own granular arrangement for plant roots to grow.

It is because soilized sand has the same mechanical properties and eco-mechanical attributes as natural soil that it serves as a favorable habitat for plant growth. Desert soilization can be applied on a large scale efficiently as follows: water is sprayed on the desert surface by an irrigating machine, the constraining material is spread on the desert surface by a mechanical spreader, and the constraining material is uniformly mixed with the surface layer of desert sand by a rotary cultivator. In this way, a layer of sand, 15–25 cm in thickness in a desert is soilized. The content of the constraining material is generally less than 0.3% at a weight ratio to sand. During sowing and planting, compound or organic fertilizers might be added to the soilized sand for better plant growth.

Sand soilization is in essence a transformation of the mechanical states of a granular material. Therefore, besides desert sand (with silica as the dominant content), soilization is also applicable to coral sand on islands (with calcium content up to 90%), Gobi sand (with large particle size distribution), and other granular materials including crushed stones, concrete, and mine wastes. Sowing and planting may start immediately after sand soilization. Within 3 months the field will be covered by full, rich vegetation. Soilized sand is suitable for various types of plants to grow, including trees, shrubs, grasses, and crops. The experimental results show that the yield and biomass of most plants in the soilized sand exceed those grown in the nearby natural soil. Third-party evaluations show that the yields of sorghum and white radish in the Ulan Buh Desert are as high as 11,835 kg and 205,485 kg per hm², respectively, whereas with similar amounts of fertilizer the average yield of sorghum is 4,860 kg and that of white radish no more than 75,000 kg per hm² in China. The root biomass (Figures 1H and 1I) is generally 2–7 times higher than that of the comparative natural soil samples. Under the same management conditions including irrigating and fertilizing in the same desert, the biomass of plants in the soilized sand increases by an order of magnitude compared with that in the non-soilized sand (Figures 1J and 1K). Such high yields and biomass could be due to two reasons. One is that soilized sand retains water, nutrients, and aeration. The other lies in the unique profile of soilized desert: a soilized sand layer underlaid by discrete sand granules. At the soilized Ulan Buh Desert, the prolific growth of plants attracted different kinds of animals rarely seen in deserts, such as frogs, foxes, badgers, and rabbits. Inspection results show that the constraining material is environmentally friendly and that agricultural products from the soilized desert have received “green food” certification in China. The constraining material only needs to be added once. Subsequent sowing and planting do not affect the mechanical properties of the “soil” as rotten plant roots form new ODI constraints among the soilized sand granules. Operational taxonomic unit analysis shows that the microbial richness and diversity of the soilized sand samples are comparable to and even exceed those of the natural soil samples within one year after soilization and planting.

It is especially noteworthy that the soilized desert has a strong water-saving effect. In the Ulan Buh Desert where the annual precipitation is approximately 100 mm, a plot of soilized desert in 12 hm² continues to be fully covered by heat-tolerant plants such as Artemisia annua and Astragalus adsurgens without artificial irrigation except for germination in the first year (Figure 1L). For the growth of non-psammophytes in the soilized desert, artificial irrigation is necessary. However, the amount of irrigation is much less than the local water-saving irrigation quota for natural soil. The experiments in the Ulan Buh Desert have proved that the average irrigation amount for vegetables, fruits, and crops is less than 6,000 tons per hm², whereas the local water-saving irrigation quota is 8,250 tons per hm². In the desertified grassland in Zoige, Sichuan Province, where the annual precipitation is approximately 600 mm, full vegetation coverage is achieved without any artificial irrigation.

Human activities have consumed numerous high-quality land resources, such as forests and grasslands, on Earth. However, deserts, covering over one-fifth of the global land area, have hardly been utilized. Worse still, desertification is spreading to encroach upon additional valuable land resources. In fact, not all the existing deserts on Earth are born deserts. For example, the Ulan Buh Desert mentioned earlier was once a fertile land during the Han Dynasty of China (202 BC to 8 AD). Desertification, as a big ecological threat to human survival and development, is still waiting to be resolved. Desert soilization will provide an efficient approach to ensure arable land and food security, as well as to address the world’s most serious sustainability challenges resulting from CO₂ emissions. With the large-scale application of desert soilization, the dream of making deserts bloom will no longer be far away.

REFERENCES
1. Shukla, P.R., Skea, J., Calvo Buendia, E., et al. (2019). IPCC, 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf.
2. Yi, Z.J., and Zhao, C. (2016). Desert “soilization”: an eco-mechanical solution to desertification. Engineering 2, 270–273.
3. Yi, Z., Zhao, C., Gu, J., et al. (2016). Why can soil maintain its endless eco-cycle? The relationship between the mechanical properties and ecological attributes of soil. Sci. China Physics, Mech. Astron. 59, 89–90.
4. Reynolds, J.F., Smith, D.M., Lambin, E.F., et al. (2007). Ecology: global desertification: building a science for dryland development. Science 316, 847–851.
5. Cheng, H. (2020). Future earth and sustainable developments. The Innovation 7, 100055. https://doi.org/10.1016/j.xinn.2020.100055.

DECLARATION OF INTERESTS
The authors declare no competing interests.