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News & Focus

Desert "Soilization": An Eco-Mechanical Solution to Desertification

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Desertification refers to the degradation of land [1–4]. As a severe global environmental problem, it has drawn considerable attention from the international community. *The United Nations Convention to Combat Desertification* [4] was adopted by the United Nations in 1994, and since that time, countries around the world have made ever-increasing efforts to combat desertification [5–12]. However, the spread of desertification has not been controlled. Instead, it is becoming even worse; it is expanding at a rate of 50 000–70 000 km^2 annually [13,14]. At present, desert and other dryland regions endangered by global desertification account for 41.3% of Earth's land area [2,15–17]. In China, the desertified land is approximately 1.73×10^6 km^2 which is 18.03% of the national territory, and another 3.1×10^5 km^2 is tending to be desertified [18].

Desert control poses a global challenge. Presently, there exist three prevailing types of methods of desert control [1,9–12,19]: engineering methods, chemical methods, and vegetation methods. These methods have all played a positive role in desert control. The principle of engineering methods is to prevent the drifting of sand by building barriers, such as straw checkerboard barriers and sand fences. Chemical methods involve spraying oil, bitumen or latex onto the surface of sand to cause the surface layer to solidify. In vegetation methods, sand is usually remediated through the planting of psammophytes. However, none of the above methods is capable of changing the material characteristics of sand into those of soil.

The proposition of desert "soilization" is based on the realization of sand "soilization," which presents a promising alternative to the prevailing methods of desert control. Sand "soilization," i.e., the turning of sand into "soil," is a remarkable transformation based on the revelation of the eco-mechanical attributes of soil. It has been found by Yi et al. [20] that the mechanical properties and ecological attributes of soil are closely correlated. Soil is in a rheological state when wet and in a solid state when dry, and it can readily transform between these two states. These mechanical properties of soil endow it with the two eco-mechanical attributes of self-repair and self-regulation. An analysis by Yi et al. [20] has shown that these two attributes are the prerequisites for soil to maintain its endless eco-cycle and to serve as an ideal habitat for plants. If these two attributes are lost, then the soil will degrade, and one of two scenarios may emerge: soil hardening or soil desertification. Based on the above finding, sand "soilization" has been achieved by Yi et al. by imposing an appropriate constraint among the sand granules.

Sand, as it is defined in geology or engineering [19,21], exists in a discrete state, and the constraint that acts among its granules is a contact constraint. When a suitable water-based paste is added to and mixed with sand granules, then an omni-directional integrative (ODI) constraint (with omni-directionality and restorability) will form among the granules instead, and the sand will be transformed into a rheological state (wet "soil") [20]. After the evaporation of the water content in the paste, the ODI constraint will transition into a fixed constraint, and the sand will transform into a solid state (dry "soil"). "Soilized" sand possesses the mechanical properties of natural soil, which can continuously transform between the rheological state and the solid state. Thus, such "soilized" sand possesses the same eco-mechanical attributes as those of soil. Because the necessary constraint is imposed on the sand granules by means of a water-soluble paste, this "soilized" sand also possesses a strong capacity to retain water, nutrients, and air. Clearly, there is no significant difference between the "soilized" sand and natural soil in terms of their mechanical properties and ecological attributes. Yi [22] has found that once sand is "soilized," it becomes suitable for the growth of plants, thus making it an ideal habitat for plants.

Since 2013, we have been conducting an outdoor planting experiment at two sites (with areas of approximately 550 m^2 and 420 m^2, respectively) in the Nan'an District of Chongqing, China. Desert landform conditions were simulated in the experiment by establishing a 15-cm- to 25-cm-thick plain sand layer underlain by a 20-cm- to 30-cm-thick gravel layer on the ground. Afterward, three types of "soilized" sand layers with thicknesses of 10–20 cm, which were obtained by mixing sand with a modified sodium carboxymethyl cellulose (CMC) solution (containing 2% modified CMC and 5% compound fertilizer) at a weight ratio of 1∶0.15, were placed on top of the plain sand layer in separate sections. Three types of commercially available sand for building and construction (clean river sand), with different fineness moduli of 1.22, 2.97, and 3.71 and without any soil content, were subjected to "soilization" for the experiment. In addition to these river sands, three other granular materials (machine-made sand from stone, sand mixed with machine-made sand from stone, and sand mixed with saw-dust) were also used in the planting experiment after "soilization." Many types of plants (Fig. 1(a)), such as rice (Fig. 1(b)), corn (Fig. 1(c)), and sweet potatoes (Fig. 1(d)), were planted in the "soilized" sand. In each year of the experiment, the

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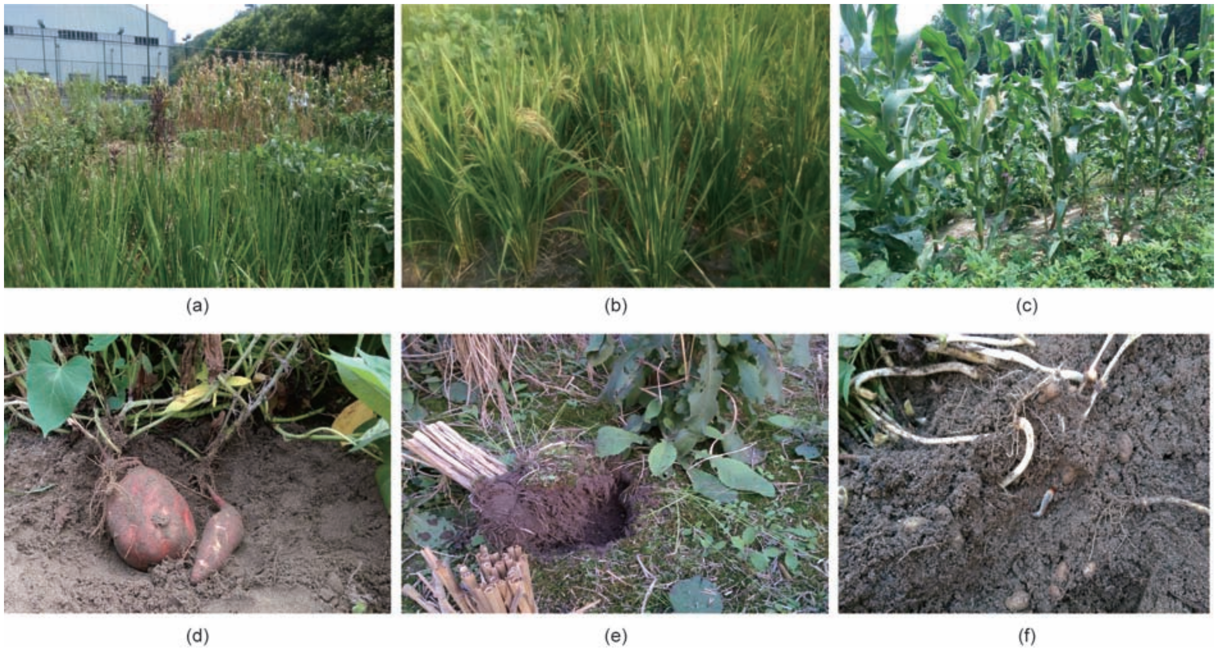

Fig. 1. "Soilized" sand: an ideal habitat for plants. (a) Various plants planted in "soilized" sand; (b) rice growing in "soilized" fine sand; (c) corn growing in "soilized" coarse sand; (d) sweet potatoes growing in "soilized" moderate-grain sand; (e) after the harvest (of rice), the "soilized" sand remained in good condition, and the algae on the surface of the "soil" demonstrated that the constraint introduced into the "soil" could not be washed away by water; (f) insect larvae appeared in "soilized" sand.

plants have survived the heavy rains and continuous high temperature over consecutive sunny days that are characteristic of the climate in Chongqing, China. During these periods of continuous high temperature, the plants have been appropriately watered at different intervals. The constraining material was added to the "soils" only once in the spring of 2013, and no further supplementation has been made to the "soils" after that, except for the addition of an appropriate amount of fertilizer each year since 2014. There have been two harvests each year, and the plants have always grown luxuriantly and fruitfully in the different "soils." In the years 2014 and 2015, the comparison of the yields of the plants including corn, potatoes, sweet potatoes, radish, and oilseed rape was made with those grown in the nearby fields of natural soil. The results show that all yields in the experiment field were higher, and in particular, the yields of three plants (potatoes, sweet potatoes, and radish) with tuber or tuberous roots were 50% higher (with the reasons and underlying mechanism to be elaborated upon in our next paper on eco-mechanics of soil). The planting experiment proves that the "soilized" sand has not turned back into its original discrete state by the erosion of rainstorm. On the contrary, the plots that were watered more frequently (for example, the plot in which rice was planted) have been found to be heavily covered with algae (Fig. 1(e)). Our planting experiment further shows that the eco-mechanical attributes of the "soilized" sand have been further improved throughout the cycle of planting and cropping, with the "soilized" sand behaving increasingly similarly to natural soil. Three months after the first harvest, organisms such as ants, earthworms, centipedes, and insect larvae had already appeared in the "soil" (Fig. 1(f)).

The planting experiment described above verifies that "soilized" sand is an ideal habitat for plants and that its eco-mechanical attributes can be retained over the long-term.

Desert "soilization," i.e., the "soilization" of the surface layer of desert sand, is an unprecedented scientific proposition. The essence of desert "soilization" is to enable surface sand to acquire the mechanical properties and ecological attributes of soil. In principle, desert "soilization" is the inverse process of desertification. Desert "soilization" has the potential to make deserts bloom, improve the ecological environment in desert regions, and, ultimately, benefit mankind.

To verify the feasibility of desert "soilization," in April 2016, we started a large-scale planting experiment in "soilized" sand in the Ulan Buh Desert, the Inner Mongolia Autonomous Region, China. Covering an area of approximately 10 000 km^2, the Ulan Buh Desert is located at approximately 1100 m above sea level. This desert is characterized by little rainfall, with an average annual precipitation of only 102.9 mm, and severe wind erosion. It is one of the most severely desertified regions in China and one of those that are most difficult to control. Our experimental field is located at 39°36′32″N, 106°39′02″E in the Ulan Buh Desert with the altitude of 1110 m above the sea level (Fig. 2). Because the underground water resources in Ulan Buh Desert are quite abundant (the reserve volume is approximately 5.7×10^9 m^3), all of the water used to convert the sand into "soil" and for the irrigation of the plants growing in it is sourced from underground water. In the experiment, the content of added constraining material, such as modified CMC, in the sand is between 0.1% and 0.4%. The desert sand and the constraining material were first mixed using a mixer and then paved onto the desert surface with an average thickness of 10 cm (Fig. 2(a)). A nitrogen-phosphorus-potassium compound fertilizer was also added at a weight ratio of 0.3% with respect to the sand. The "soilized" sand possesses a strong water retention capability (Fig. 2(b)). A spray atomization irrigation system was used in the experiment (Fig. 2(c)). In an attempt at large-scale mechanized preparation, we even used a rotary cultivator to mix the "soilized" sand and apply it over an area of 2000 m^2, and the results suggest that such a mechanized preparation approach is feasible for large-scale desert "soilization" (Fig. 2(d)). Approximately 50 different plant seeds or seedlings, including *Festuca arundinacea*, coreopsis, wheat, corn, sunflower, sand jujube tree, and poplar tree, were sowed in the experimental field (Fig. 2(e)) beginning on May 20th, 2016. At present, more than 70 kinds of plants (over 20 of which may have been introduced by wind or birds) are growing healthily and robustly in the field (Fig. 3(a)–(e)),