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Soil treatment using microbial biopolymers for anti-desertification purposes

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ABSTRACT

Desertification and soil degradation are becoming more serious due to global warming and concurrent extreme climate events. Although anti-desertification efforts have been mounted worldwide, most undertakings have shown poor performance because of failure to consider soil and geotechnical aspects. Soil erosion is accelerated by reductions in soil cohesion and water retention due to the transfer of fine particles from the original ground. Thus, soil internal cohesion must be recovered to ensure effective and reliable anti-desertification attempts. In this study, soil treatment using biopolymers is suggested as an alternative method to prevent soil erosion and for revitalization, taking into consideration engineering and environmental aspects. Even as a relatively small part of the soil mass (i.e., 0.5–1.0%), biopolymers in soil have the positive potential to significantly reduce the erodibility of soil by enhancing inter-particle cohesion. Moreover, biopolymer treatment also improves both vegetation germination and soil water retention characteristics against evaporation, and therefore can provide suitable environments for plants and crops used as a desertification countermeasure in arid and semi-arid regions where annual precipitation is limited. We suggest combining biopolymers with pre-existing anti-desertification efforts (e.g., afforestation and windbreaks) on desert fronts (i.e., boundaries between arid and semi-arid regions) for best efficiency.

1. Introduction

Annually, 12 million ha of the Earth's landmass (the same size as the state of Mississippi) turn into new deserts (United Nations Environment Programme, 2006). Currently, more than 30% of the Earth's dry land is affected by desertification, and this trend, transforming land into deserts, is expanding into semiarid regions. From the perspective of geoscience and geotechnical engineering, the critical factors affecting land erosion and desertification are limited precipitation and the removal of soil particles (especially fines < 0.002 mm) (Schlesinger et al., 1990).

The mechanism of soil erosion is generally known to be an interaction between the drag force of fluids (e.g., wind or water) and soil shear resistance (Morgan, 2005). Although water erosion is the largest source of global soil erosion, wind erosion is the major geomorphological force in desertified regions (Blanco and Lal, 2008). Airborne particles produced by wind erosion consist of high amounts of clay minerals (Gillette and Walker, 1977), and most global aeolian dust originates from North Africa (58%), the Middle East (12%), and West China (11%), regions which directly coincide with desertified areas (Tanaka and Chiba, 2006; UNEP/RIVM, 2004). Nonetheless, water erosion is another serious problem, because the immediate intensity of soil erosion produced by water is reported to be higher and more critical than wind erosion in areas that are undergoing desertification (e.g., grasslands in semi-arid regions) (Breshears et al., 2003). Moreover, the total amount of erosion produced by water is reported to be two times larger than the amount affected by wind erosion worldwide (Lal, 1995). Therefore, not only control of aeolian dust, but also enhancement of soil resistance to water erosion (i.e., undrained shear strength) should be considered in desertification prevention approaches.

Generally, greater amounts of clayey particles and higher organic content in soils promote higher erosion resistance, by enhancing structural binding and aggregation between soil particles (Blanco and Lal, 2008). An investigation of the particle size distributions and compositional data from 88 sites around the world (Fig. 1) shows that desertification has a high correlation with change in soil composition (i.e., loss of fine particles). Soils from ‘stable regions’ (i.e., low vulnerability, such as tropical or rain forests) are well graded and have very fine soil contents,

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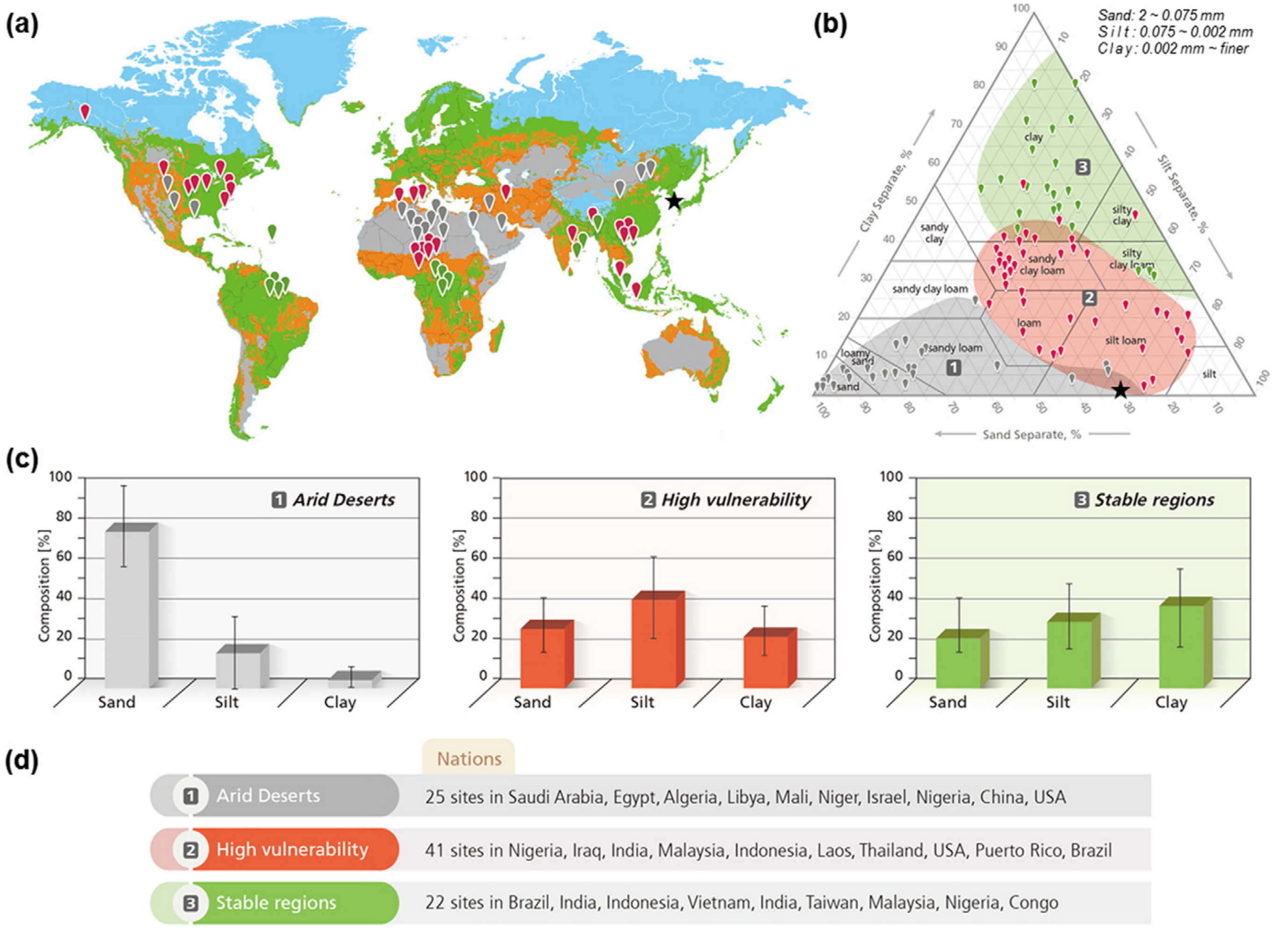

Fig. 1. Relationship between desertification and soil composition transfer (★ indicates the soil used for laboratory testing in this study). (a) Desert vulnerability map. (b) Tripartite graph of soils collected from 88 sites. (c) Soil composition. (d) Nations with sites investigated.

while 'arid desert' soil becomes poorly graded with a biased soil component (i.e., sand).

The classification of 'arid deserts', 'high vulnerability', and 'stable regions' comes from the desert vulnerability map (United Nations Environment Programme et al., 1997) which classifies regions in terms of destruction of vegetal cover, ground erosion, reduction in surface flow, loss of soil productivity, etc. (Reich et al., 1999). The evolution of soil composition illustrated in the soil tripartite graph (Fig. 1) shows that desertification involves the transformation of well graded soil in stable regions into poorly graded soil (sand content higher than 50%) due to the loss of fine soil particles (annually 3–80 tons/ha in highly vulnerable regions) by water or wind erosion (Balba, 1995; Reich et al., 1999). Thus, the loss of clay particles (i.e., decrease of interparticle cohesion of soil) is the most critical problem in desertification. This explains why deserts are generally composed of sand and rocky surfaces with a sparseness of vegetation.

In terms of geoscience the recovery of soil strength by enhancing soil cohesion is therefore very important as a countermeasure to desertification. However, in practical terms, it is impossible to supplement the sands of all arid or semi-arid regions with cohesive fine soils. As an alternative, we present herein a new concept to enrich soil cohesion using biological materials (i.e., biopolymers).

Sugar based biopolymers (polysaccharides) produced by microorganisms are widely used in food (e.g., dairy products) and medical industries. Previous studies have shown the possibility of using biopolymers to reduce soil erosion (Agassi and Ben-Hur, 1992; Gu and Doner, 1993; Orts et al., 2000), strengthen soil (Chang and Cho, 2012; Chang et al., 2015), and control water infiltration (Ben-Hur and Letey, 1989; El-Morsy et al., 1991) in agricultural and geotechnical practices. This paper reports several experimental studies which were performed to obtain a better understanding of the effects of biopolymer treatment for comprehensive soil revitalization and prevention of desertification. When a soil was mixed with even a little amount of biopolymer, we found that the presence of these hydrophilic biopolymers produced interesting soil characteristics, especially relevant in terms of anti-desertification.

2. Materials and methods

2.1. Microbial excrements: biopolymers

In this study, commercial β-glucan (Polycan™, β-1,3-glucan from *Aureobasidium pullulans*) and xanthan gum (CAS No. 11138-66-2) were used to represent high molecular chain type, and gel (gum)-forming (i.e., hydrocolloid) type biopolymers, respectively. The β-glucan (molecular weight: 1000–2000 kDa) from *A. pullulans* is a homopolysaccharide consisting of β-1,3-glycosidic linked glucose units with some branched β-1,6-glucose, which can exceed 150–5400 kDa depending on the continuity of glucosidic bonding between D-glucose monomers (Hamada, 1990). In contrast, anionic xanthan gum (molecular weight: 2000–20,000 kDa) secreted by *Xanthomona campestris* is a heteropolysaccharide with a primary structure consisting of repeated pentasaccharide units formed by two glucose units, two mannose units, and one glucuronic