An Environmentally-Friendly Geotechnical Approach for Soil Erosion Reduction Using Microbial Biopolymers

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Abstract: Global warming and unsustainable land development are known to be major triggers promoting geotechnical hazards such as farmland and coastal erosion, yellow dust, and desertification. New forestry practices, such as encouraging forests in dry land areas, are simple measures that can remove more carbon from the atmosphere and prevent the spread of deserts. Numerous global agencies and companies are thus contributing to anti-desertification movements. However, tree planting alone is not an ideal solution given that it takes approximately 2~3 years for stabilization. It is thus imperative to develop innovative technology that can promote vegetation growth and improve soil erosion resistance. In this study, a unique soil treatment and anti-desertification method is developed using environmentally friendly biogenic biopolymers. Biopolymers can effectively strengthen soil and improve durability. In particular, anionic-hydrophilic biopolymers delay water evaporation, thereby retaining a higher soil moisture condition compared to untreated soil. For technical verification, series of laboratory investigations (*i.e.* water erosion test, seed germination and growth,) were performed by applying target biopolymers to soil specimens. The results indicate that environmentally-friendly biopolymer treatment is highly effective in improving both vegetation growth (3 times faster) and soil erosion resistance (less than 2%), compared to a untreated condition.

INTRODUCTION

Annually, 12 million hectares 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 (Fig. 1). 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.

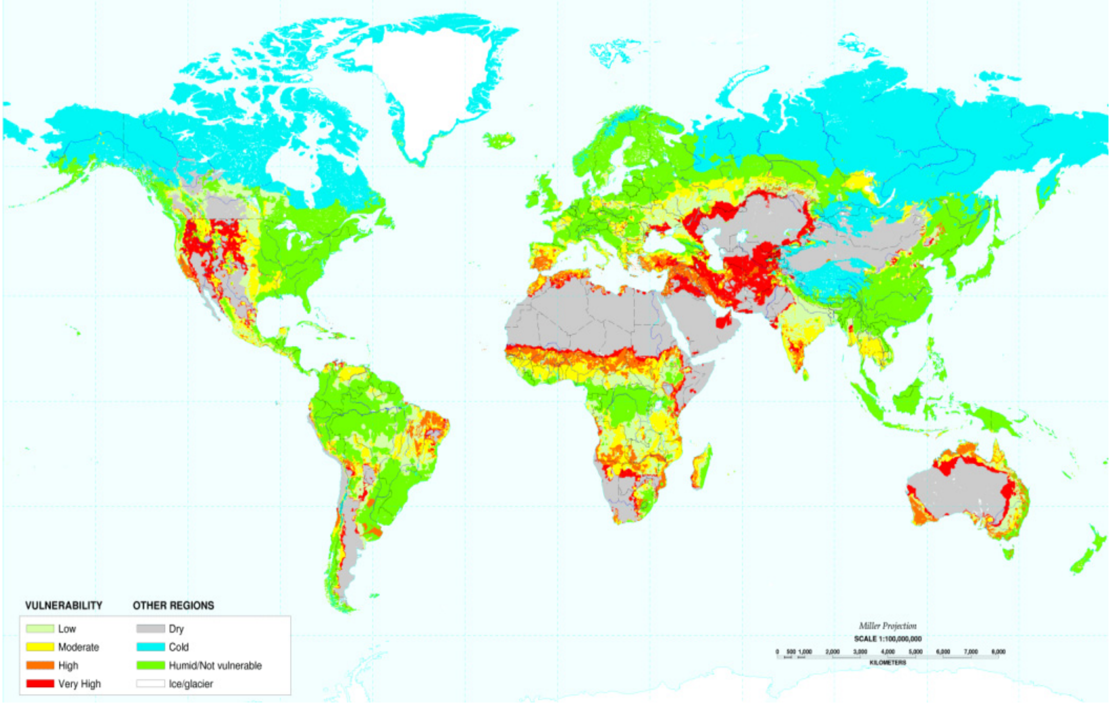

FIG. 1. World map of soil erosion and desertification (after UNEP 2006)

During the last half century the Chinese government has engaged in a large-scale (*i.e.*, 2.2 billion ha) afforestation program called the "Three North's Forest Shelterbelt". However, the costly effort has yielded little success, while concurrent expansion of the deserts in China has occurred, with inexorable growth ratios of 1,560 km^2/yr (1950-1975), 2,100 km^2/yr (1976-1988), and 3,600 km^2/yr after 1998 (Wang et al. 2008; Wang et al. 2010). One of the biggest reasons for this failure is known to be that previous massive planting efforts were performed without addressing the recovery of soil cohesion and moisture. An individual tree planted in cohesionless arid or semiarid soil can disturb the flow of air, creating turbulence and localized wind erosion on the ground around the tree trunk. As a result, trees roots were exposed and withered under the strong sunlight and limited moisture (Cao 2008). The failure of previous attempts provides a lesson about the importance of both inter-particle cohesion and soil moisture retention for soil revitalization in afforestation projects in arid and semi-arid regions.

In geotechnical engineering aspects to recover the soil strength and erosion resistance 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, this study presents a new concept to enrich soil cohesion using biological materials (*i.e.*, biopolymers)

EXPERIMENTAL PROGRAM

Biopolymers and soil

Beta-glucan biopolymer

Beta-1,3/1,6-glucan is a biopolymer of D-glucose monomers linked by glycosidic bonds (Bacic et al. 2009). Beta-glucan has various formations in nature such as cellulose in plants, bran of cereal grains, and cell walls of yeast, fungi, mushrooms, and bacteria.

A modified liquid type β-1,3/1,6-glucan biopolymer product (Polycan^{TM}; Glucan Corp., Busan, Korea) produced by *Aureobasidium pullulans* SM-2001 is used in this study (Shin et al. 2007). The β-1,3/1,6-glucan content of Polycan^{TM} is 8.9 g/L. Thus, previous study attempted the optimal β-1,3/1,6-glucan content to the mass of soil as 5 g/kg, when 1 kg of dried soil is mixed with 600 g (*i.e.* 60 % water content) of liquid phase pure Polycan^{TM} (Chang and Cho 2012).

Xanthan gum biopolymer

Xanthan gum is an anionic polysaccharide composed of D-glucuronic acid, D-mannose, pyruvylated mannose, 6-O-acetyl D-mannose, and a 1,4-linked glucan (Cadmus et al. 1982). The best well known characteristic of Xanthan gum is pseudo plasticity (viscosity degradation depending on increase of shear rate). Moreover, Xanthan gum shows high stability under a wide range of temperatures and pH (Davidson 1980). Recently, xanthan gum biopolymer is adopted to improve the inter-particle bonding of soils through direct hydrogen bonding formation with clayey particles (Chang et al. 2015).

Korean residual soil

Korean residual soil (*i.e. hwangtoh*) is used in this study. *Hwangtoh* has a mineral constitution (by mass) as: quartz (8.4%), kaolinite (45.8%), halloysite (22.7%), illite (14.8), and goethite (8.3%). The natural soil was oven dried at 110°C (ASTM 2007), and was then grinded (grain size < 75 μm) for testing. Korean residual soil has been actively adopted in several previous studies on biopolymer soil treatment (Chang and Cho 2012; Chang and Cho 2014; Chang et al. 2015)

Biopolymer-soil mixing and erosion simulation

Three different soil conditions for water erosion simulation were prepared separately as: a) natural (untreated) soil, b) 0.5% β-1,3/1,6-glucan biopolymer treated, and c) 0.5% Xanthan gum biopolymer treated. The amount of soil was fixed as 2,000 g for all cases.

For water erosion, the angle was set to be 20° using a step incliner. For a single erosion step, 500 mL of water was sprinkled which simulates raining on the soil surface. The weight of specimen was measured before and after raining. Eroded slurry was collected and its volume and mass were measured simultaneously. Slurry was dried in an oven to evaluate the absolute amount of eroded solids (Fig. 2).

FIG. 2. Laboratory precipitation simulation of soils to evaluate the erosion resistance of biopolymer treated soils.

To simulate moderate raining condition, the period between each cycle was controlled to be 48 hrs. After a single erosion process, the specimens were left in room to be naturally dried. To simulate heavy raining, the period between each cycle was shortened as 10 mins. Other procedures were same as abovementioned.

RESULTS AND ANALYSES

Biopolymers and soil

The laboratory water erosion test results are summarized in Fig. 3. Fig. 3 represents the cumulated ratio of total erosion compared to the initial amount (2,000 g) of solid soil. Biopolymer treated conditions show significant low erosion ratio (*i.e.*, 2% in average), while untreated natural soil exceeds 21.2% to 60% depending on the different rain density (*i.e.*, moderate and heavy) applied for erosion simulation.

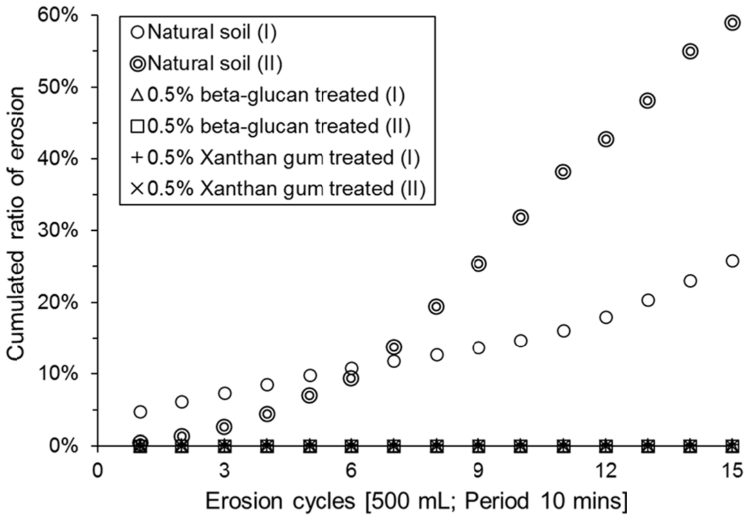

FIG. 3. Cumulated ratio of erosion with subsequent precipitation simulations.

Tables 1 and 2 summarize the erosion tendency under different rain intensities. Under moderate rain simulation, the total amount of erosion for untreated soil reaches 21.2%, while exceeds up to 60% under heavy raining for the same soil geometry (*i.e.*, untreated). However, in the case of biopolymer treated soils, biopolymer treated soils show higher erosion resistance under heavy raining, regardless of biopolymer type. For moderate rain simulation, all specimens were fully dried before the subsequent raining simulation, which render cyclic swelling and dehydration of biopolymers inside soil. Thus, the lower erosion resistance of biopolymer treated soils under moderate rain simulation seems to be affected by the structural disturbance of biopolymers which were subjected to cyclic wetting and drying, while biopolymers under heavy precipitation remained moist without extreme drying.

Table 1. Erosion result of moderate rain simulation

Soil treatment	Cumulated ratio of erosion [%]									
	1	2	3	4	5	6	7	8	9	10
Untreated	4.8	5.8	7.7	9.6	11.2	12.5	15.3	17.7	19.7	21.2
Beta-glucan	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.05	0.1	0.1
Xanthan gum	0.8	0.9	1.0	1.0	1.0	1.0	1.1	1.2	1.2	1.3

Table 2. Erosion result of heavy rain simulation

Soil treatment	Cumulated ratio of erosion [%]									
	1	2	3	4	5	6	7	8	9	10
Untreated	0.4	1.3	2.6	4.4	7.0	13.8	25.3	38.2	48.1	59.0
Beta-glucan	0	0	0	0	0	0	0	0	0	0
Xanthan gum	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

The higher erosion resistance under heavy rain simulation can be also recognized in Fig. 4. As totally 15 cycles of rain were applied in 140 mins, the total amount of erosion of untreated soil expands to 60%, while β-1,3/1,6-glucan treated soil shows nearly no erosion.

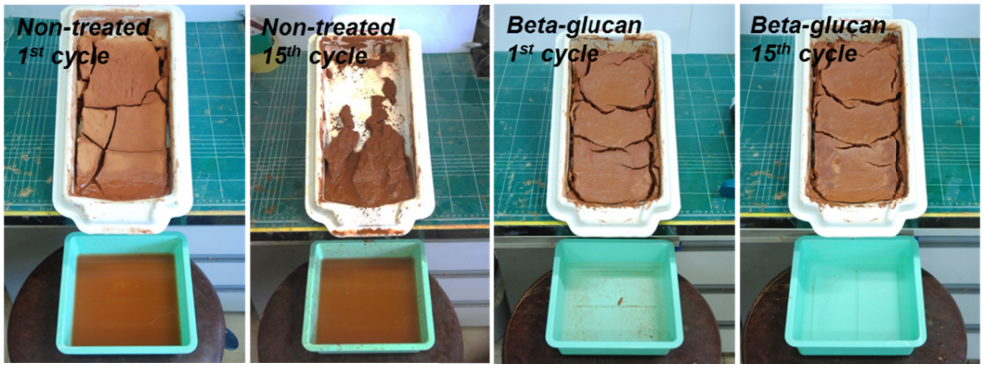

FIG. 4. Water erosion test results. Comparison between untreated and beta-glucan treated soil.

For moderate rain simulation, the period between cycles was 48 hrs. The drying tendency of untreated soil is faster than biopolymer treated soil because hydrophilic biopolymers interrupt moisture loss from soil. Thus, in the case of untreated soil, considerable amount of water infiltrates into soil at every cycle which diminishes surface rush off.

However, in the case of heavy raining, erosion accelerates after the 4th cycle. This is induced by the fully saturated condition due to continuous water supply. Meanwhile, biopolymer treated condition shows higher erosion resistance compared to moderate raining. Water sprinkled on biopolymer mixed soils suddenly flows down without any interaction with the soil surface. This indicates that the biopolymer treated soil has low permeable coats on its surface.

CONCLUSIONS

In this study, a unique soil treatment and anti-desertification method is suggested using environmentally friendly biogenic biopolymers. Biopolymers can effectively improve the strength and durability (*i.e.* stability) of soil.

In particular, anionic-hydrophilic biopolymers delay water evaporation, thereby retaining a higher soil moisture condition compared to untreated soil. Moreover, biopolymer matrices in soil enlarge soil voids which provide improved cultural environment for crops. In the aim of erosion prevention, laboratory water erosion simulation results show that environmentally-friendly biopolymer treatment is highly effective in improving soil erosion resistance (less than 2%), compared to a untreated condition.

Therefore, biopolymer treatment can be carefully concluded as an effective alternative for anti-desertification and eroded land recovery (*e.g.* revegetation). Further studies are necessary for deeper and more theoretical understandings on the functional benefits of biopolymer treatment to prevent soil erosion and desertification

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