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Restoration of eroded coastal sand dunes using plant and soil-conditioner mixture

Sun Hwa Hong, Eun Young Lee*

Department of Environmental and Energy Engineering, The University of Suwon, Gyeonggi, 445-743, Republic of Korea

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A B S T R A C T

In this study, we evaluated the ability of a soil-conditioner mixture to reduce soil erosion of coastal sand dunes. Plant growth-promoting rhizobacterium *Bacillus* sp. SH1RP8 was isolated from indigenous plants normally found in coastal sand dunes. Potassium polyacrylate, a superabsorbent polymer, was applied as a soil-conditioner to evaluate the promotion of *Arundo donax* growth in sand dunes at Songjeong beach (site A) and Soongut beach (site B), South Korea. This soil-conditioner mixture increased the shoot length of *A. donax* cultivated for 10 months at both the sites, specifically 167.52% at site A and 122.78% at site B, whereas shoot biomass increased by 370.64% and 149.30%, respectively. The viable cell count of strain SH1RP8 was maintained during the vegetation restoration period. Soil containing *A. donax* lost soil at a rate of 1.61% when it was watered daily for 8 days (2 L/day), whereas the loss was 55% in the control plots. These results indicate that the soil-conditioner mixture containing SH1RP8 can serve as a promising microbial inoculant for increasing plant growth in coastal sand dune environments, and for improving the phytostabilization efficiency and preventing soil erosion.

1. Introduction

Coastal sand dunes are an important habitat and have environmental and economic value; thus, it is important to protect coastal regions and conserve the associated plants inhabiting them (Maun and Baye, 1989; Martinez et al., 1997). In particular, coastal sand dunes have various functions such as sand and underground water storage, while they also are a habitat for rare plants (Han et al., 2013). However, owing to typical coastal conditions (including rapid topographical changes, strong winds, intense sunlight, high levels of salinity, water shortage, sand erosion, and extreme dryness), the habitat available for living organisms is very limited (Maun, 1994; Martinez et al., 1997). Consequently, plants inhabiting this terrestrial ecosystem cannot reseed easily; furthermore, this region is populated by plants rarely found in other locations (Han et al., 2013). However, coastal sand dunes are vanishing because of environmental development, contamination, anthropogenic damage, and soil loss caused by natural disasters (Opelt and Berg, 2004; Lee et al., 2006). Thus, although there are various methods to restore damaged coastal sand dunes, the plantation of native vegetation is the preferred method since it is eco-friendly and conserves the scenic aspects of these habitats (Hong et al., 2012). Unfortunately, owing to specific environmental conditions of coastal sand dunes, research focused on how these plants is limited (Hong et al., 2012).

The diverse communities of vegetation in costal sand dunes vary depending on the relocation of nutrient salts and the inclination of sand dunes due to the degree of sand erosion, range of soil temperature change, inorganic nutrient gradients, pH, earthiness, and presence of blown sand (Costa et al., 1996; Yu and Rhew, 2007). In particular, plants inhabiting sand dunes, which are vulnerable physical habitats, are adapted to unique environments since they can breed in vines, grow by firmly fixing the shoot with developed roots, or form leaves and stems that protect against strong sunshine and water evaporation (Carter, 1991). Vegetation located in sand dunes prevents sand loss driven by physical factors such as waves (Hong and Lee, 2014), decreases the velocity of sand movement owing to wind, and leads to sedimentation, thus it is an effective and natural way to protect coastal sand dunes (Carter, 1991). Previously, we developed soil loss prevention technology for coastal sand dunes using striped reeds that can simultaneously purify water and fix sand with their developed shoots, which stabilizes coastal sand dunes owing to rapid vegetation settlement. We developed a soil-conditioner mixture composed of plant growth-

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* Corresponding author. Tel.: +82 31 220 2614.
E-mail address: ley@suwon.ac.kr (E.Y. Lee).

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promoting rhizobacteria (PGPR), namely *Bacillus* sp. SH1RP8, as well as an ion exchange resin, and a super absorbent polymer (SAP) for the rapid stabilization of the striped reed, *Arundo donax* (Hong and Lee, 2014; Hong et al., 2015). PGPR was used to improve germination, anthesis, and plant growth during the phytostabilization of sand dunes (Hong and Lee, 2014), and we utilized ion exchange resin to reduce salt accumulation, which is the most problematic disturbance to phytostabilization in sand dunes (Hong and Lee, 2014). Additionally, we used SAP with a high capacity for water retention (Hong et al., 2015; Liu and Chan, 2015), in order to avoid moisture deficiency that can be caused by salt stress and high temperatures (Greenway and Munns, 1980). Also, when the plants are overexposed to water from rainfall and irrigation, SAP can regulate the amount of the water and improve germination efficiency, anthesis, and crop production (Azzam, 1983; Blodgett et al., 1993). When in contact with water, the polymer transforms into a stationary gel-phase by absorbing water equivalent to of hundreds to thousands times of its weight. Also, after absorbing water, the polymer superior levels of water retention and rarely discharges water even under a certain degree of pressure; therefore, it is possible to control moisture levels. (Zhang et al., 2007). We thus previously identified the best method for the improvement of plant growth and rapid phytostabilization in lab-scale mesocosm studies that replicated the environment of coastal sand dunes and analyzed the effect of the addition of a unique soil-conditioner mixture (Hong and Lee, 2014; Hong et al., 2015).

To further expound upon our previous results, here, we evaluated the efficiency of the soil-conditioner mixture in the field, by demonstrating its efficiency not only in a lab-scale experiment but also in a sand dune environment. An additional goal included 1) developing an efficient method for phytostabilization by monitoring vegetation changes and rhizobacterium across all four seasons. After phytostabilization, 2) we evaluated the influence of vegetation on soil loss in coastal sand dunes, by calculating the soil loss ratio in relation to the presence of vegetation.

In 2007, the Korea Ocean Research and Development Institute reported that the sea surface along the east coast of Korea annually rose 6.4 cm over the course of the past 14 years owing to climate change, which is greater than the average global oceanic change (sea surface 3.1 mm/yr). Consequently, coastal erosion is at the forefront of problems that must be addressed. On the east coast, coastal erosion occurs mainly on sandy flat beaches. It has been reported that coast erosion has accelerated recently owing to built revetments and buildings that have altered the natural sand movement in beaches and sand dunes (Hwang et al., 2010). According to previous studies by Kim and Kim (2010), coastal erosion is predicted to result in damage to facilities and territorial loss, and to the destruction of natural spaces, including the reduction of the surface area of sandy beaches, a unique asset of the east coast of Korea. Therefore, planned management of currently problematic regions is necessary, and it has been suggested that coastal areas experiencing erosion should be designated as disaster prevention sectors to be used to manage coastal sand dunes on the east coast (Kim and Kim, 2010). Consequently, we designated the problematic areas on the east coast as our field study sites, to be used to evaluate the efficiency of the soil-conditioner mixture previously developed.

2. Materials and methods

2.1. Study areas (site A and site B)

The target areas for this study were: a coastal sand dune in Songjeong beach in Gangwon province (site A) located at 37°78′ north latitude, 128°94′ east longitude, and a coastal sand dune in Soongut beach (site B) located at 37°82′ north latitude, 128°89′ east longitude (Fig. 1). The coastal sand dunes of the east coast that were selected as field study sites representative of the coastlines in Korea. It is warmer in the winter and cooler in the summer than the west coast and inland region along the identical latitude owing to the influence of Mt. Taebaek and the Kuroshio Current (Kim et al., 1994). The average annual temperature of the main regions along the east coast is 12.6 °C, which is 0.1 °C lower than the national average annual temperature, while the average annual rainfall is 1276.11 mm, which is 31.59 mm less than the national average (Han et al., 2013; http://www.kma.go.kr). Finally, compared to the west coast along the identical latitude, the sand dunes cover a larger area.

2.2. Effects of the soil-conditioner mixture on plant growth in the field

On May 15, 2014, we installed experiment strips approximately 10 m^2 in size in two coastal sand dunes (site A and site B). Striped reeds, *Arundo donax*, with an average length of 17–22 cm were planted at both sites. For this, we dug spaces in the sand dunes 15 cm deep, added 0.5 cm of soil-conditioner mixture, a product made by combining 5% (w/w) freeze dried *Bacillus* sp. SH1RP8, 90.25% (w/w) ion exchange resin (Hong and Lee, 2014), and 4.75% (w/w) SAP (potassium polyacrylates) (Hong et al., 2015), then covered the mixture with 5 cm of sand, and finally planted *A. donax*. In each of the two conditions (one was the untreated control plot, and the other the experimental plot treated with the soil-conditioner mixture), 80 seedlings were planted (Fig. 2). Over the course of ten months after the experiment, we measured the growth of the plants on the following five occasions: June 16, July 11, August 4, September 4, and October 10 of 2014. Since the plants did not grow in length during winter, we collected soil samples without measuring plant length and quantified the amount rhizobacteria (May 2014 through March 2015). After the experiment, we collected the plants and assessed biomass. Subsequently, we compared plants from the control plots with those from the experimental plots to evaluate the efficiency of the developed soil-conditioner mixture. Plants were carefully sampled from the field, oven-dried at 70 °C for 3 days and divided into shoots and roots, after which the biomass of each sample was measured.

2.3. Assessment of Bacillus sp. SH1RP8 abundance after inoculation in the field

Bacillus sp. SH1RP8 was inoculated in the sandy soil at both site A and site B, and microbial abundance was monitored in samples using real time PCR (RT-PCR). To design the TaqMan probe and primers, the 16S rDNA from *Bacillus* sp. SH1RP8 was amplified by PCR using the primers 27f (AGA GTT TGA TCM TGG CTC AG; M = C:A) and 1492r (TAC GGY TAC CTT GTT ACG ACTT; Y = C:T) (Martin-Laurent et al., 2001). PCR amplification was performed under the following conditions: an initial denaturation step at 95 °C for 5 min, 28 cycles of denaturation at 95 °C for 30 s, annealing at 60 °C for 30 s, extension at 72 °C for 30 s, with a final extension step at 72 °C for 5 min (Hong and Lee, 2014). The amplified 16S rDNA was purified using a PCR purification kit (Qiagen, Germany), and then sequenced. The sequences were analyzed using the Basic Local Alignment Search Tool (BLAST), a service available from GenBank (Hong and Lee, 2014). Based on the search results, unique partial sequences of *Bacillus* sp. SH1RP8 were identified, with which the novel TaqMan probe and primers for *Bacillus* sp. SH1RP8 were designed. The TaqMan primers were 5′-ACG ATG AGT GCT AAG TGT TAG G-3′ for the forward primer and 5′-CCC AGG CGG AGT GCT TAA TG-3′ for the reverse primer. The probe sequence was 5′-TTC CGC CCC TTA GTG-3′ and was labeled at the 5′ end with FAM (6-