Journal of Architectural Research and Development, 2024, Volume 8, Issue 6
https://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Study on the Wind Erosion Resistance of Desert Soil Induced by Bacillus Megaterium

Jingyuan Yin[1,2]*

[1]College of Life and Geographic Sciences, Kashi University, Kashi 844000, China
[2]Key Laboratory of Biological Resources and Ecology of Pamirs Plateau in Xinjiang Uygur Autonomous Region, Kashi 844000, China

Corresponding author: Jingyuan Yin, jingyuan2077@126.com

Abstract: With the intensification of global climate change and the worsening of land degradation, desertification has emerged as a significant global issue threatening ecosystems and human activities. The technique of Microbial Induced Calcium Carbonate Precipitation (MICP) has been widely applied in soil stabilization and engineering geology in recent years. This study conducts experiments using Bacillus megaterium to solidify desert sand via MICP, aiming to explore its feasibility as a novel ecological method for desert protection. Experimental results indicate that desert sand treated with MICP exhibits a significant enhancement in wind erosion resistance, providing a potential solution for desert management and land restoration.

Keywords: MICP; Soil stabilization; Wind erosion resistance

1. Introduction

1.1. Desertification and its global impact

Desertification is regarded as one of the most severe environmental threats facing global ecosystems, impacting not only the natural environment but also directly threatening human survival and development. According to the United Nations Convention to Combat Desertification (UNCCD), over 12 million hectares of land are lost annually due to desertification, affecting the livelihoods of one billion people worldwide [1]. Desertification leads to land degradation and food security issues, triggering socio-economic problems such as migration, increased poverty, and conflict. Regions severely affected by desertification include sub-Saharan Africa, parts of the Middle East and North Africa, certain areas of South America, and arid and semi-arid regions in Asia, particularly in Northwest China [2]. As climate change intensifies and population pressures increase, the issue of desertification has become more urgent, posing a formidable challenge to global ecological security [3].

1.2. Impact of dust storms on the environment and humanity

Dust storms, as a concomitant phenomenon of desertification, frequently occur in arid and semi-arid regions, posing significant threats to both the environment and human health. Wind erosion not only depletes soil by removing organic matter and minerals but also damages plant root systems and disrupts regional water cycles and climate patterns [4]. For instance, the frequent spring dust storms in Northern China not only harm local ecosystems but also negatively impact air quality in downwind countries and regions [5]. Once these dust particles enter the atmosphere, they can easily cross borders and affect air quality and climate change as far away as North America and Europe [6]. Additionally, dust storms lead to increased traffic accidents, respiratory diseases, and infrastructure damage, imposing a substantial burden on economic development [7].

1.3. Current status and limitations of windbreak and sand fixation technologies

To combat the harms of desertification and wind erosion, various countries have adopted a range of windbreak and sand fixation technologies, such as vegetation restoration, mechanical windbreaks, and chemical stabilizers. Vegetation restoration is a common ecological measure that stabilizes soil and reduces wind erosion by planting drought-resistant plants [8]. However, in extremely arid environments, the effectiveness of vegetation restoration is often limited due to water scarcity and poor soil quality, requiring substantial funding and long-term maintenance. Moreover, extreme weather conditions associated with climate change make it difficult for vegetation to survive long-term, further restricting the adoption of this technology [9].

Mechanical windbreaks, such as sand barriers and grids, can effectively block wind and sand in the short term, but their high costs and complex maintenance make large-scale implementation challenging. Chemical stabilizers, another effective technology, enhance soil wind resistance by altering its physical and chemical properties. However, their potential environmental toxicity and high costs hinder widespread application [10].

1.4. The rise of microbial-induced calcium carbonate precipitation technology

In recent years, scientists have begun to explore the use of biotechnology for windbreak and sand fixation, particularly through the MICP technique. This technology utilizes microbial metabolic activities to induce calcium carbonate precipitation, thereby enhancing soil strength and stability. This method has significant advantages in terms of environmental protection and sustainability, as the microbial-induced calcium carbonate precipitation process resembles natural mineral deposition, providing long-term soil stabilization and reducing soil loss [11].

The application prospects of MICP technology are vast, especially under extreme climatic conditions, as it can serve as an efficient, low-cost, and sustainable solution. Furthermore, this technology has minimal adverse environmental effects, avoiding the common pollution issues associated with chemical stabilizers. Although MICP has shown promising results in laboratory and small-scale trials, its large-scale application still faces technical challenges, such as controlling microbial activity and improving induction efficiency [12].

1.5. Objectives and significance of the study

This study aims to explore the application potential of MICP technology under wind erosion conditions, particularly its effectiveness in different wind speed scenarios. By comparing traditional windbreak measures with MICP technology, this research will provide a theoretical foundation and technical support for future large-scale applications. The findings will not only offer new insights for desertification control in arid and semi-arid regions but also contribute to mitigating the impacts of dust storms on human society and the environment, thereby enhancing global ecological security [13].

2. Methods

2.1. Materials and methods

2.1.1. Study area and climatic conditions

The experimental site selected for this study is located in a typical desertification area of arid and semi-arid regions in Northwest China. This area, situated in the Kashi, exhibits a typical continental climate with extremely low annual precipitation of only 50 mm, while the annual evaporation exceeds 2,000 mm. The region is characterized by widespread desert, frequent wind erosion activities, and high average annual wind speeds of 6.2 m/s, with frequent dust storms in spring. The severity of desertification in this area is evident in land degradation, soil salinization, sparse vegetation, and loss of biodiversity. The selection of this study area is based on its typical desertification characteristics and the testing requirements for MICP technology. The sandy conditions in this region provide valuable reference data for testing the effectiveness of MICP technology and its subsequent application.

2.2. Materials

2.2.1. Sand samples

The sand samples used in the experiments were collected from the top layer (0 cm to 30 cm) of typical desertified soil in the study area. The soil, after weathering, consists of medium to fine sand particles with a diameter ranging from 0.1 mm to 1.0 mm. Sample preparation involved naturally air-drying the collected sand to remove organic matter and other impurities, followed by sieving to eliminate particles larger than 2 mm to ensure consistency and repeatability in the experiments. The physical and chemical properties of the soil were determined through laboratory analysis, including particle size distribution, organic matter content, pH, and moisture content. The specific characteristics of the sand samples are as follows:

(1) Particle size distribution: 85% between 0.1 mm to 0.5 mm, 15% between 0.5 mm to 1.0 mm.
(2) pH: 8.1.
(3) Organic matter content: < 0.5%.
(4) Moisture content: 5%.

2.3. Microbial culture medium and strains

The primary strain used for the Microbial Induced Calcium Carbonate Precipitation (MICP) technology is a highly efficient urea-decomposing strain of the Bacillus genus. This strain is capable of rapidly hydrolyzing urea and producing calcium carbonate precipitation through its metabolic activities. The selection of this strain is based on its adaptability to extreme environments and its high urea hydrolysis activity. To ensure microbial activity, a standard peptone water medium was used, supplemented with urea and calcium chloride as substrates for inducing the precipitation reaction. The cultivation conditions for the strain were maintained at 30°C in a constant temperature incubator with a pH of 7.0. To maximize strain activity, the cultivation time before each experiment was limited to 24 hours, ensuring that the bacterial cells were in the logarithmic growth phase.

3. Experimental design

3.1. MICP experimental design

This study employs a combination of field simulation experiments and laboratory experiments to evaluate the effectiveness of MICP technology in wind erosion resistance under varying wind speeds and environmental conditions. The experimental design consists of the following three steps.

3.1.1. Microbial cultivation and preparation of biological treatment solution

For the MICP experiments, Bacillus megaterium, known for its excellent calcium precipitation ability, was utilized. The specific cultivation process is as follows:

(1) Medium preparation: LB medium (10 g/L peptone, 5 g/L yeast extract, 10 g/L sodium chloride) was used as the basic nutrient source for bacterial culture.
(2) Cultivation conditions: The bacteria were incubated at 37°C in a constant temperature shaker for 24 hours until the bacterial concentration reached an OD600 of 1.0.
(3) Preparation of bacterial suspension: Following cultivation, the bacterial suspension was centrifuged (4,000 rpm for 10 minutes), and the supernatant was discarded. The bacterial pellet was resuspended in sterile water to achieve the desired concentration (1.0 × 10^8 CFU/mL). Subsequently, a urea precipitation solution was prepared with an initial urea concentration of 1.0 M, mixed with the cultured bacterial suspension in a 1:1 ratio to obtain the final biological treatment solution.

3.1.2. Spraying treatment of precipitation solution

The prepared precipitation solution was uniformly sprayed onto the surface of the sand samples at a rate of 200 ml/m^2. Various types of treatment solutions were set up, including the biological treatment solution, urea solution, and distilled water, to investigate the effects of different treatments on sand fixation effectiveness.

3.1.3. Wind tunnel experiment

To simulate wind erosion conditions in a natural environment, a wind tunnel was employed to simulate wind erosion environments at different wind speeds. Three groups of comparative experiments were designed:

(1) Biological treatment group: Sprayed once with bacterial suspension and urea solution.
(2) Urea treatment group: Sprayed only with urea solution.
(3) Distilled water treatment group: Sprayed only with distilled water.

Each sand sample weighed 570 g. After treatment, the samples were maintained in the laboratory for 24 hours before being placed in the simulated wind tunnel, where wind erosion experiments were conducted for 8 minutes at wind speeds of 3 m/s, 6 m/s, 9 m/s, 12 m/s, and 15 m/s. The mass of the sand samples was recorded before and after the experiments to calculate mass loss due to wind erosion, as shown in **Table 1** and **Figure 1**.

Table 1. Data of wind erosion quality (g)

Wind speed (m/s)	**3**	**6**	**9**	**12**	**15**
Biological treatment	4.41	5.89	10.84	21.57	55.36
Urea treatment	256.18	369.57	570	570	570
Distilled water treatment	299.34	483.03	570	570	570

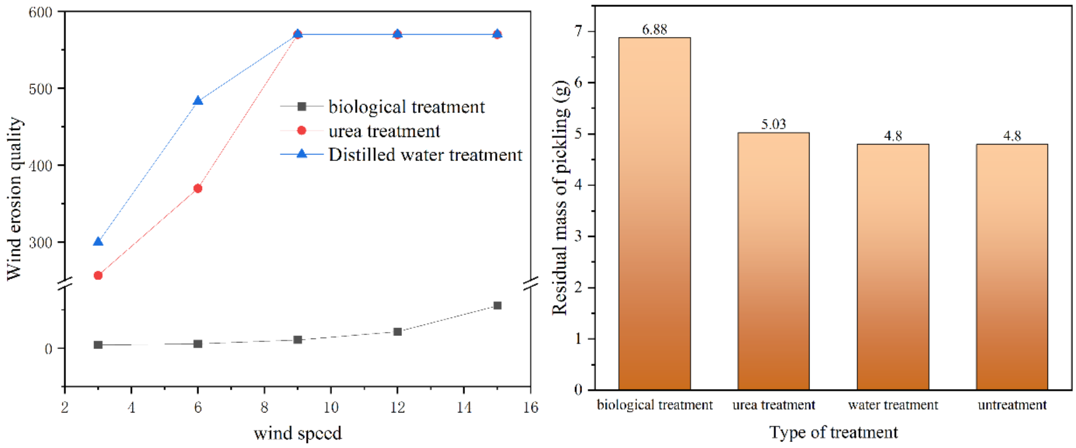

Figure 1. Data of wind speed and residual mass of pickling on different treatment types

4. Data collection and analysis

The primary data collected during the experiments included:

1. Soil wind erosion resistance: The changes in wind erosion resistance of the sand samples before and after treatment were assessed by recording the mass loss. The residual mass of each group of sand samples was weighed at the end of each experiment to calculate the wind erosion mass.
2. Calcium carbonate precipitation amount: The amount of calcium carbonate generated was measured by acid washing the treated soil samples.

4.1. Data measurement and analysis

The initial and post-experimental masses of the sand samples were measured using a high-precision electronic balance (accuracy of 0.01 g).

5. Results and discussion

5.1. Comparison of wind erosion resistance

According to the experimental results, the bacterial suspension + urea treatment group exhibited a significant advantage in wind erosion resistance. Under varying wind speed conditions, particularly at the lowest wind speed (3 m/s) and highest wind speed (15 m/s), the mass losses for this group were 0.41 g and 5.77 g, respectively, significantly lower than those of the other treatment groups. This indicates that MICP technology effectively enhances the wind erosion resistance of the sand samples through microbial-induced calcium carbonate precipitation. Although mass loss increased with wind speed, this treatment group maintained relatively low loss amounts, demonstrating the stabilizing effect of the calcium carbonate precipitation layer on the particles.

5.2. Comparison between the urea treatment group and the distilled water treatment group

In the experiments involving the urea treatment group and the distilled water treatment group, both groups experienced maximum mass loss (570 g) when wind speeds reached 9 m/s or above, indicating that the soil samples had nearly completely lost their wind erosion resistance. Even at lower wind speeds (3 m/s and 6 m/s), both groups exhibited significant mass loss. This suggests that neither the urea treatment nor the distilled water treatment had a substantial effect on improving the wind erosion resistance of the sand samples, failing to produce effective particle stabilization and deposition reactions.

5.3. Mass analysis after acid washing

5.3.1. Untreated and distilled water treatment groups

The mass of sand after acid washing for both groups was 4.8 g, indicating that distilled water treatment had no significant effect on restoring the mass of the sand samples. During the acid-washing process, both groups lost a considerable amount of surface particles and binding materials, and could not stabilize or deposit back into the samples, leading to low wind erosion resistance.

5.3.2. Urea treatment group

The mass of the sand samples treated with urea after acid washing was 5.03 g, slightly higher than that of the untreated and distilled water treatment groups. However, due to the absence of microbial activity, the amount of calcium carbonate precipitation was limited, resulting in only marginal improvement in wind resistance. This slight increase in mass may be attributed to ionic deposition from urea, but it was insufficient to significantly enhance the stability of the sand.

5.3.3 MICP treatment group

The mass of the sand samples treated with MICP after acid washing was 6.88 g, significantly higher than that of the other treatment groups. Through microbial-induced calcium carbonate precipitation, this treatment markedly increased the bonding strength between soil particles, forming a stable layer that resisted dissolution during the acid washing process. The calcium carbonate deposition effectively enhanced the structural integrity of the sand, greatly increasing its wind erosion resistance.

6. Conclusion

The experimental results demonstrate that MICP technology significantly enhances the wind erosion resistance of desert soil through microbial-induced calcium carbonate precipitation, particularly under high wind speed conditions, effectively reducing mass loss of the sand. In contrast, the urea treatment and distilled water treatment did not significantly improve the soil’s wind resistance, yielding only minimal effects. Therefore, MICP technology shows great potential in combating desertification, especially in arid regions severely affected by wind erosion, with broad application prospects.

Disclosure statement

The author declares no conflict of interest.

References

[1] United Nations Convention to Combat Desertification (UNCCD), 2022, Global Land Outlook 2.

[2] Smith P, Calvin K, Nkemet J, et al., 2020, Which Practices Co-Deliver Food Security, Climate Change Mitigation and Adaptation, and Combat Land Degradation and Desertification? Global Change Biology, 26(3): 1532–1575.

[3] Bao Y, Cheng L, Yang L, et al., 2017, Desertification: China Provides a Solution to a Global Challenge. Frontiers of Agricultural Science and Engineering 4(4): 402–413.

[4] Anderson DT, 1966, Soil Erosion by Wind: Cause, Damage, Control.

[5] Zhang L, 2016, Causes and Prevention of Dust Storm Weather in Northern Regions. Modern Agriculture, 2016(07): 109–110.

[6] Firor J, 1990, The Changing Atmosphere: A Global Challenge. Yale University Press, Connecticut.

[7] Goudie AS, Middleton NJ, 2001, Saharan Dust Storms: Nature and Consequences. Earth-Science Reviews, 56(1–4): 179–204.

[8] Rehacek D, Khel T, Kucer J, et al., 2017, Effect of Windbreaks on Wind Speed Reduction and Soil Protection Against Wind Erosion. Soil & Water Research, 12(2): 128–135.

[9] van Ramshorst JGV, Siebicke L, Baumeister M, et al., 2022, Reducing Wind Erosion Through Agroforestry: A Case Study Using Large Eddy Simulations. Sustainability, 14(20): 13372.

[10] Shakeel AM, 2016, Stabilization of Soil Using Chemical Additives. Global Research and Development Journal for Engineering, 1(12): 2455–5703.

[11] Seifan M, Berenjian A, 2019, Microbially Induced Calcium Carbonate Precipitation: A Widespread Phenomenon in the Biological World. Applied Microbiology and Biotechnology, 103: 4693–4708.

[12] Yu T, Souli H, Péchaud Y, et al., 2022, Optimizing Protocols for Microbial Induced Calcite Precipitation (MICP) for

Soil Improvement–A Review. European Journal of Environmental and Civil Engineering, 26(6): 2218–2233.
[13] Liu J, Li G, Li X, 2021, Geotechnical Engineering Properties of Soils Solidified by Microbially Induced CaCO3 Precipitation (MICP). Advances in Civil Engineering, 2021(1): 6683930.