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A research on harnessing MICP for soil erosion control: A sustainable approach for thar desert's soil

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Abstract

Soil erosion is a critical environmental issue, particularly in arid regions like the Thar Desert, where wind erosion accelerates land degradation. This study explores the application of Microbially Induced Calcium Carbonate Precipitation (MICP) as an eco-friendly solution for enhancing soil stability and mitigating erosion. Laboratory experiments were conducted using Sporosarcina pasteurii to induce calcium carbonate precipitation in sandy soil. The research assessed changes in soil properties, permeability, and erosion resistance through physicochemical analysis, wind tunnel testing, and unconfined compressive strength (UCS) measurements. The results demonstrated a significant reduction in porosity (18%), permeability (80%), and wind erosion mass loss (73%), alongside a 360% increase in UCS. Microscopic analysis confirmed the formation of a calcite crust, enhancing soil cohesion. This study highlights MICP's potential as a sustainable erosion control strategy, offering a viable alternative to conventional soil stabilization methods.

Keywords: Soil Erosion; Soil Conservation; Desertification; MICP; Sporosarcina Pasteurii; Calcium Carbonate Precipitation; Wind Erosion; Soil Stabilization; Thar Desert

1. Introduction

1.1. Overview of Soil Erosion

Soil erosion is a natural process influenced by wind, water, and human activities, leading to the displacement of soil particles. This phenomenon reduces soil fertility, impacts water quality, and alters ecosystems. While natural erosion occurs over long periods, accelerated erosion due to deforestation, agriculture, and construction significantly degrades land. Effective management strategies, including vegetation cover, contour farming, and structural interventions, help in mitigating its adverse effects. (Pimentel et al., 1995).

1.2. Types and Causes of Erosion

Erosion can be categorized into different types based on causative factors:

- **Water Erosion**: Includes splash, sheet, rill, and gully erosion, predominantly occurring in regions with heavy rainfall and poor vegetation cover.
- **Wind Erosion**: Common in arid regions where loose soil particles are carried away by wind, leading to land degradation and desertification.
- **Glacial and Coastal Erosion**: Involves the movement of soil and rock due to glaciers and wave action, reshaping landscapes over time.

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- **Anthropogenic Erosion**: Human-induced erosion from deforestation, construction, and unsustainable agricultural practices further accelerates soil loss and degradation.

1.3. Key Factors Contributing to Soil Erosion

- **Natural Causes**: Strong winds, sparse vegetation, and harsh climatic conditions.
- **Human Activities**: Overgrazing, deforestation, and unsustainable agricultural practices accelerate erosion

1.4. Historical and Global Perspective

India has long faced soil erosion challenges, particularly due to monsoon-driven weather patterns and agricultural dependency. Traditional conservation methods such as contour farming and afforestation have been used to mitigate erosion (Chopra et At, 1993). However, rapid industrialization and urbanization have intensified the problem. On a global scale, the United Nations has identified soil degradation as a critical issue, emphasizing sustainable land management practices.

1.5. Impacts of Soil Erosion

1.5.1. Soil erosion in the Thar Desert results in:

- **Wind Erosion**: Loss of topsoil due to high wind velocity, reducing soil fertility.
- **Desertification**: Progressive land degradation making the soil unsuitable for agriculture.
- **Sand Encroachment**: Movement of sand dunes affecting farmlands, settlements, and infrastructure.
- **Water Resource Depletion**: Increased siltation in reservoirs and reduced water retention capacity.
- **Biodiversity Loss**: Habitat destruction leading to decreased flora and fauna populations.

1.6. Remediation Strategies

1.6.1. Preventive and corrective measures are essential to combat erosion:

- **Vegetative Methods**: Planting cover crops, agroforestry, and grass barriers help stabilize the soil (Lal et al., 2001).
- **Structural Approaches**: Check dams, terracing, and retention basins reduce runoff and sediment displacement.
- **Innovative Techniques**: Microbially Induced Calcium Carbonate Precipitation (MICP) is being explored as an eco-friendly method to enhance soil stability.

1.7. Research Objectives and Scope

1.7.1. This study explores MICP as a potential solution for erosion control in arid regions. Key objectives include:

- Assessing MICP's effectiveness in improving soil cohesion and erosion resistance.
- Identifying optimal conditions for microbial activity in soil stabilization.
- Comparing MICP with conventional erosion control techniques.
- Evaluating the economic and environmental feasibility of MICP applications.

The research focuses on desert regions, analysing soil characteristics, optimizing MICP application, and conducting field validation to determine its practicality. Findings will contribute to developing sustainable soil conservation strategies.

2. Literature Review

2.1. Overview of Soil Erosion Research

Soil erosion is a critical environmental issue affecting agricultural productivity, water quality, and ecosystem stability. Extensive research has been conducted to understand its causes, impacts, and mitigation strategies. This chapter reviews key studies that contribute to the knowledge of soil erosion and its control measures (Sharda et al., 2013).

2.2. Cultural and Ecological Approaches

Traditional practices such as sacred groves have played a vital role in soil conservation. Research by Chopra et al. (1993) highlights how sacred groves function as natural erosion barriers by preserving vegetation cover, which reduces surface runoff and stabilizes soil.

2.3. Soil Conservation Prioritization

Narain et al. (1998) emphasized the importance of identifying high-risk erosion areas for effective conservation planning. Their framework for prioritizing erosion-prone regions aids in resource allocation and mitigation efforts.

2.4. Erosion and Climate Change

Studies by Ghosh et al. (2012) illustrate the connection between climate change and erosion, indicating that increased rainfall variability accelerates soil loss. Adaptive conservation strategies are essential to counteract these effects.

2.5. Modern Conservation Techniques

Morgan (2005) compiled comprehensive research on erosion processes and mitigation strategies. His work provides insights into physical, chemical, and biological conservation methods, including contour plowing, mulching, and vegetative barriers.

2.6. Role of Remote Sensing and GIS

Jain et al. (2021) demonstrated the use of remote sensing and GIS technology to monitor and predict soil erosion patterns. These tools enhance the precision of conservation planning by identifying erosion hotspots.

2.7. Wind Erosion in Arid Regions

Research by Kumar et al. (2020) and Das et al. (2018) explored the impact of wind patterns on soil degradation, particularly in the Thar Desert. Their findings support the implementation of afforestation and windbreaks to mitigate wind erosion.

2.8. Advances in Soil Stabilization

Emerging techniques such as Microbially Induced Calcium Carbonate Precipitation (MICP) have gained attention for their potential in soil stabilization. Studies by Zhang et al. (2018) highlight the effectiveness of chemical binders in improving soil cohesion in arid regions.

2.9. Policy and Community Engagement

Sharda and Dogra (2013) analyzed the role of government policies in soil conservation. Their research underscores the importance of integrating policy measures with community participation to ensure sustainable land management.

2.10. Research Gaps and Future Directions

Despite advancements, challenges remain in integrating traditional and modern conservation techniques. Further research is needed to optimize MICP applications, assess long-term impacts, and develop cost-effective erosion control strategies.

3. Materials and Methodology for MICP-Based Soil Stabilization

3.1. Soil Sampling and Preparation

The study was conducted in the Thar Desert, specifically in Jaisalmer (GPS: 26°51'42.5"N 70°35'00.5"E). Surface soil samples were collected from a depth of 0-15 cm using augers and stored in sterile, labeled bags. The collected sand was air-dried and sieved using a 2 mm mesh to remove large debris. These prepared samples were then stored under controlled conditions for further laboratory analysis.

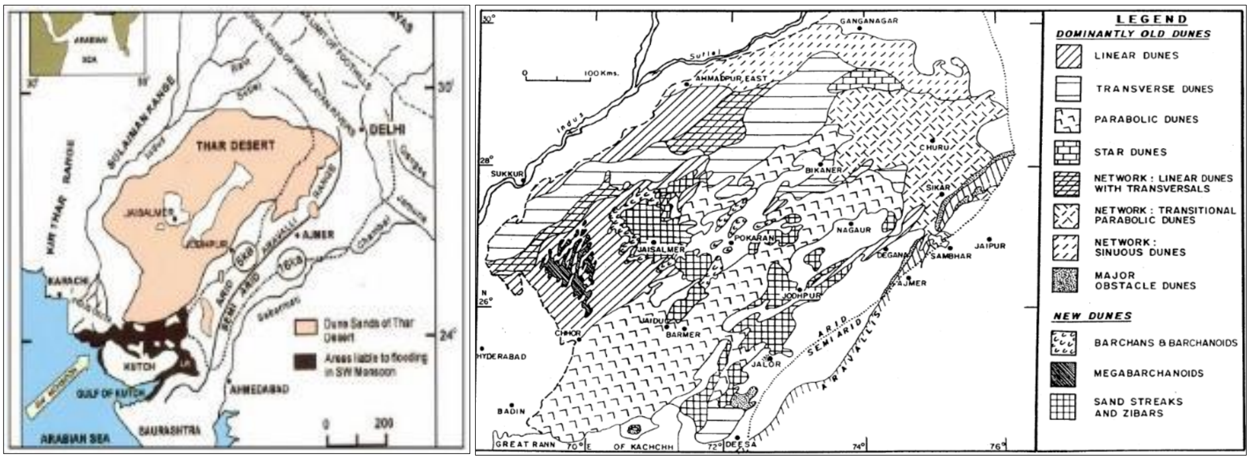

Figure 1 Location of Thar Desert

3.2. Bacterial Culture Preparation

The bacterium *Sporosarcina pasteurii* was used for MICP due to its high urease activity. The bacterial culture was prepared in a nutrient broth containing peptone (5 g/L), yeast extract (3 g/L), NaCl (5 g/L), and urea (20 g/L). The pH of the medium was adjusted to 8.0. The bacteria were incubated at 30°C in a shaking incubator at 150 rpm for 24-48 hours until the optical density (OD600) reached 0.6-0.8, indicating sufficient bacterial growth.

3.3. Chemical Reagents

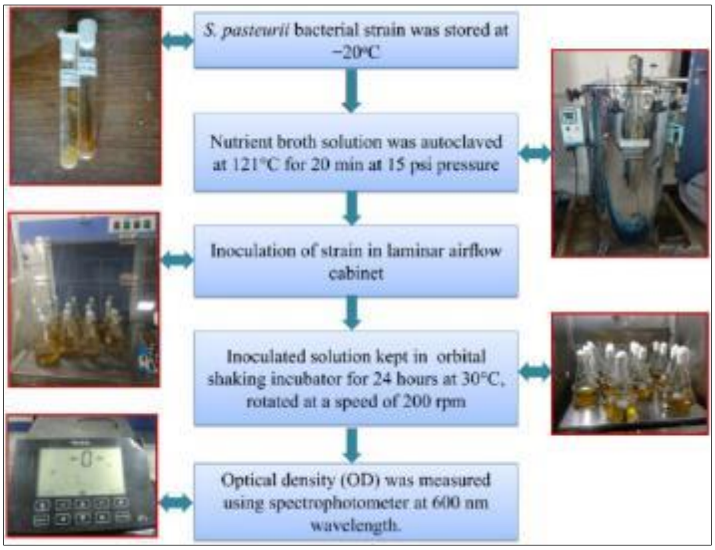

Figure 2 Preparation of Chemical Reagents

- **Calcium Chloride ($CaCl_2$):** A 0.5 M solution was prepared by dissolving 55.5 g of $CaCl_2$ in 1 L of distilled water.
- **Urea Solution (1 M):** 60 g of urea was dissolved in 1 L of distilled water.
- **Injection Medium:** A combination of nutrient broth and urea (20 g/L) was used to sustain bacterial activity during treatment.

3.4. Laboratory MICP Application Procedure

3.4.1. Experimental Setup

The experiment was conducted using two setups:

- **Column Setup:** Sand samples were placed in acrylic columns (5 cm diameter, 20 cm height) with a drainage outlet at the bottom to allow controlled flow of reagents.

- **Tray Setup:** Sand was uniformly spread in rectangular polypropylene trays (12 × 16 × 5 cm) for treatment under controlled conditions.

3.5. Treatment Process

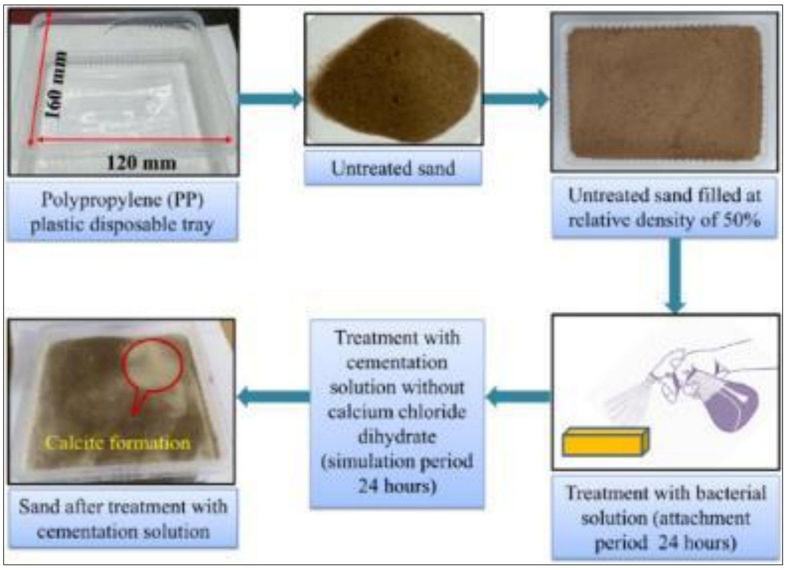

Figure 3 Application of MICP Solution

- **Bacterial Inoculation:** 500 mL of *Sporosarcina pasteurii* culture was poured into each sand sample, allowing 6-8 hours for bacteria to adhere to the sand particles and initiate urease activity.
- **Chemical Solution Application:** A 1:1 mixture of calcium chloride and urea solutions was injected into the sand daily for 5-7 days to facilitate carbonate precipitation.
- **Environmental Control:** The samples were maintained at 30°C with 5-10% moisture content to optimize microbial activity and mineral precipitation.

3.6. Process Monitoring

- **pH Analysis:** The effluent pH was monitored, with a rise to 9-10 indicating active urease hydrolysis.
- **Carbonate Precipitation:** White calcium carbonate deposits on the sand surface confirmed successful mineralization.

3.7. Post-Treatment Analysis

3.7.1. Physico-Chemical Testing

The treated samples were analyzed for key parameters, including:

- **pH and Electrical Conductivity** to assess microbial activity.
- **Porosity and Calcium Concentration** to evaluate the extent of carbonate precipitation.
- **Organic Matter and Cation Exchange Capacity** to determine changes in soil properties.

3.8. Wind Tunnel Testing

To simulate wind erosion conditions, a wind tunnel setup with a total length of 1.5 m and a 0.6 m test section was used. The treated and untreated sand samples were exposed to wind velocities of 10, 20, and 30 m/s for 1 minute. Wind velocity adjustments were made using a flapper at the air inlet, and airflow was measured with an anemometer. The weight loss of the samples was recorded before and after testing to determine erosion resistance.

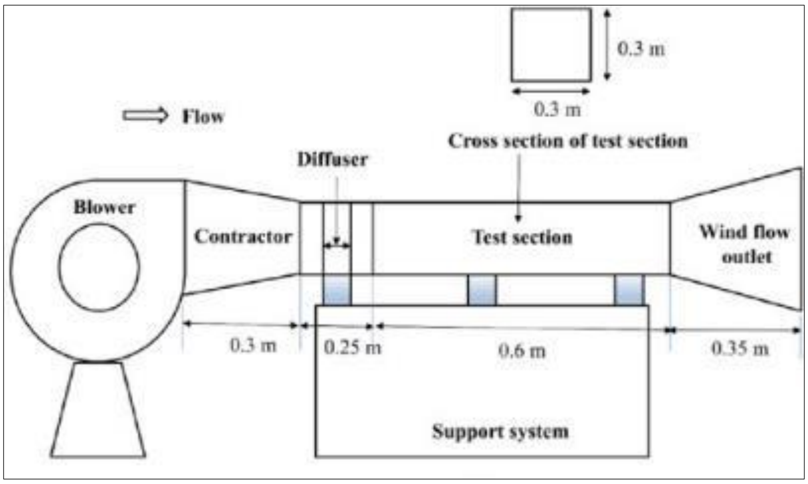

Figure 4 Wind Tunnel Diagram

4. Result and Discussion

4.1. Initial Soil Characterization

4.1.1. Physical Properties

Table 1 Physical Properties

Property	Value	Interpretation
Particle Size	Sand: 90%, Silt: 8%, Clay: 2%	High susceptibility to wind erosion
Bulk Density	1.4 g/cm^3	Loose packing, easy displacement
Porosity	35%	High water and air infiltration
Permeability	0.05 cm/sec	Rapid drainage, poor cohesion

Before applying MICP, the soil samples were evaluated to determine their physical characteristics. The particle size distribution indicated that the soil comprised 90% sand, 8% silt, and 2% clay, making it highly susceptible to erosion. The bulk density was recorded at 1.4 g/cm^3, signifying loose packing that facilitated erosion. The soil exhibited a porosity of 35%, allowing high water and air infiltration. Permeability was measured at 0.05 cm/sec, confirming the soil's high permeability and vulnerability to wind erosion.

4.1.2. Chemical Properties

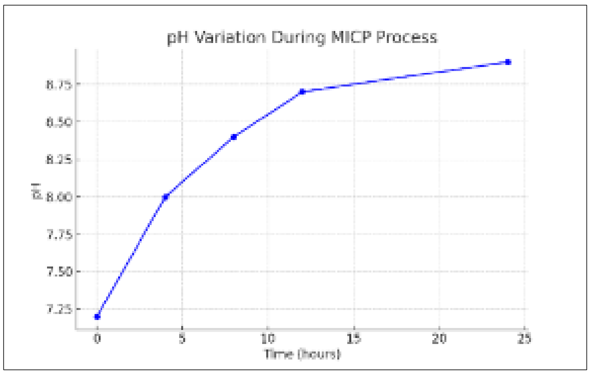

Figure 5 Variation of pH with time

The chemical composition of the soil was also assessed. The pH was recorded at 7.5, which is neutral and suitable for microbial activity. Organic matter content was found to be below 0.5%, indicating poor soil fertility. The calcium carbonate content was minimal at 2%, revealing a lack of natural cementation. These properties suggested that the soil required stabilization to prevent further degradation.

4.2. MICP Treatment Results

4.2.1. Changes in Physical Properties

- **Porosity Reduction:** Following MICP treatment, soil porosity decreased by approximately 18% due to calcium carbonate precipitation filling voids between sand particles. This reduction increased soil cohesion and resistance to wind erosion.
- **Permeability Alterations:** The permeability of the soil samples decreased significantly over three treatment cycles:

Table 2 Permeability of Sample

Cycle	Permeability (cm/sec)	Reduction (%)
Untreated Soil	0.05	-
After 1st Cycle	0.03	40%
After 2nd Cycle	0.02	60%
After 3rd Cycle	0.01	80%

- Untreated Soil: 0.05 cm/sec
- After 1st Cycle: 0.03 cm/sec (40% reduction)
- After 2nd Cycle: 0.02 cm/sec (60% reduction)
- After 3rd Cycle: 0.01 cm/sec (80% reduction)

This decrease in permeability indicated effective binding of particles by calcium carbonate, reducing water infiltration and enhancing stability.

4.2.2. Chemical Transformations

Post-treatment, the soil's pH increased to 8.9 due to ammonia production from bacterial urease activity. The calcium concentration rose by 40%, signifying substantial carbonate precipitation. Observations showed the formation of white precipitates on the sand surface, confirming enhanced cementation.

4.3. Strength Improvement

Table 3 Strength improvement of sample

Parameter	Untreated Soil	Post MICP Treatment	Improvement
Unconfined Compressive Strength UCS (kPa)	50	230	360%
Shear Strength	Low	High	Significant
Structural Integrity	Weak	Strong	Improved

4.3.1. Unconfined Compressive Strength (UCS) tests showed a significant enhancement in soil strength:

- Untreated Soil: 50 kPa
- After 3 MICP Cycles: 230 kPa (360% improvement)

The calcium carbonate deposits filled voids and bonded soil particles, forming a more cohesive structure that significantly increased resistance to erosion and mechanical stress.

4.4. Microscopic and Wind Tunnel Analysis

4.4.1. Microscopic Structural Changes

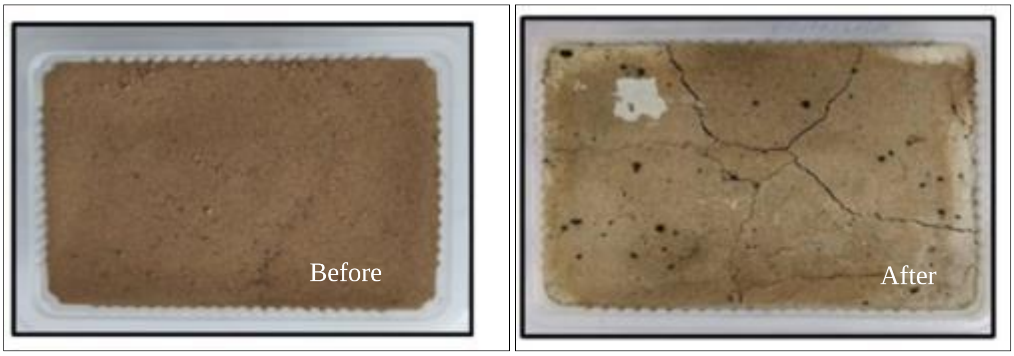

Figure 6 Before and After images of Soil sample

Untreated soil displayed a loose, granular, and dispersed structure under optical imaging. This lack of cohesion resulted in poorly bound particles, making the soil less stable and prone to erosion. However, after Microbially Induced Calcite Precipitation (MICP), the soil underwent a significant transformation. The treated samples formed a thin calcium carbonate crust, which acted as a protective layer against wind.

4.4.2. Wind Erosion Resistance

A wind tunnel experiment assessed soil erosion under controlled conditions. The mass loss of untreated soil was recorded at 150 g under a wind speed of 30 km/h. The treated samples showed significant erosion resistance:

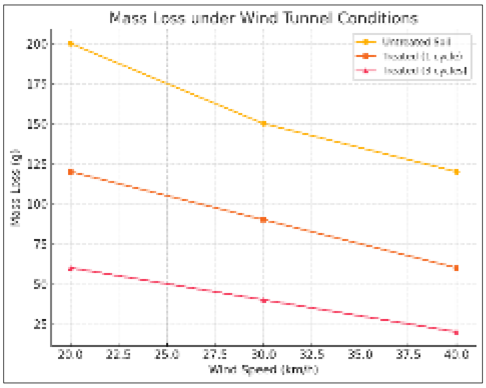

Figure 7 Mass loss of sample against wind speed

- After 1 Cycle: 90 g mass loss (40% reduction)
- After 3 Cycles: 40 g mass loss (73% reduction)

These findings confirmed that MICP treatment significantly improved soil resistance to wind erosion by binding sand particles together.

4.5. Comparative Analysis of Soil Properties

Table 4 comparison of Before and After test result

Property	Untreated Soil	Post-MICP Treatment	Improvement
Bulk Density (g/cm^3)	1.4	1.6	+14%
Shear Strength (kPa)	50	230	+360%
Permeability (cm/sec)	0.05	0.01	-80%
Erosion Resistance	Low	High	N/A

4.5.1. A comparative analysis of untreated and MICP-treated soil properties indicated:

- **Bulk Density Increase:** From 1.4 g/cm^3 to 1.6 g/cm^3 (+14%)
- **Shear Strength Enhancement:** From 50 kPa to 230 kPa (+360%)
- **Permeability Reduction:** From 0.05 cm/sec to 0.01 cm/sec (-80%)
- **Erosion Resistance Improvement:** Treated soil exhibited higher stability under wind forces.

4.6. Environmental and Sustainability Considerations

MICP proved to be an eco-friendly stabilization technique, reducing soil erosion while preserving soil chemistry. However, proper management of ammonia production is necessary to mitigate environmental risks. The method aligns with sustainable development goals by utilizing naturally occurring microbial processes for long-term soil stabilization.

5. Conclusion

This research investigated the effectiveness of Microbially Induced Calcium Carbonate Precipitation (MICP) in improving soil stability and mitigating wind erosion in arid regions. Experimental results confirmed that MICP treatment significantly enhanced soil cohesion, reducing permeability, increasing bulk density, and strengthening soil structure. The treated soil exhibited a marked improvement in resistance to wind erosion, as evidenced by a 73% reduction in mass loss during wind tunnel testing. Additionally, the formation of a calcite crust provided a protective layer, further stabilizing the soil. Compared to traditional erosion control techniques, MICP offers an environmentally sustainable, cost-effective, and durable solution for combating soil erosion. Future studies should focus on optimizing microbial application techniques and scaling up MICP implementation for field applications to support large-scale desertification control efforts.

References

[1] Benn, D. I., Evans, D. J. A., & Hulton, N. R. (2014). Glaciers and glaciation. Routledge.

[2] Chopra, K., Kadekodi, G. K., & Murty, M. N. (1993). Sacred groves as cultural and ecological heritage of India. Institute of Economic Growth.

[3] Das, S., Saha, R., & Tiwari, P. (2018). Seasonal wind patterns and soil erosion in India. Environmental Management, 61(2), 243-259.

[4] Ghosh, P., Das, S., & Chatterjee, M. (2012). Climate change and soil erosion in India: A review. Climatic Change, 114(3-4), 345-356.

[5] Hamdan, A., Shadbolt, P., & Mouli, P. (2016). Effectiveness of chemical and physical erosion control methods. Soil Science and Environmental Management, 45(2), 134-140.

[6] Jain, R., Das, A., & Srivastava, N. (2021). Advances in remote sensing and GIS for soil erosion monitoring. Indian Journal of Soil Conservation, 39(1), 67-74.

[7] Kar, A. (2014). Desertification processes in the Thar Desert: Causes and consequences. Journal of Arid Environments, 103, 1-10.

[8] Keesstra, S., et al. (2016). Soil erosion: The effects and mitigation techniques. Earth Surface Processes and Landforms, 41(9), 1236-1250.

[9] Kumar, A., Mehta, R., & Ranjan, S. (2020). Wind patterns and soil erosion: A case study of the Thar Desert. International Journal of Environmental Studies, 77(4), 489-503.

[10] Lal, R. (2001). Soil degradation: Carbon loss and management options. Science, 294(5544), 1045-1048.

[11] Lal, R. (2014). Soil erosion and agricultural productivity. Geoderma, 213, 1-12.

[12] Moghaddam, A., Rashidi, M., & Shamsabadi, H. (2020). Reforestation for soil conservation in desert areas. Forests and Arid Lands, 78(2), 175-182.

[13] Morgan, R. P. C. (2005). Soil erosion and conservation (3rd ed.). Wiley-Blackwell.

[14] Narain, P., Singh, G., & Bhushan, L. S. (1998). Assessment of soil erosion and conservation priorities. Soil and Water Conservation Research, 32(4), 67-82.

[15] Pimentel, D., & Burgess, M. (2013). Soil erosion and food security. Agriculture, Ecosystems & Environment, 181, 86-92.

[16] Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., & Blair, R. (1998). Environmental and economic costs of soil erosion and conservation benefits. Science, 267(5201), 1117-1123.

[17] Rao, S., Subramaniam, R., & Shetty, N. (2014). Integrating traditional and modern soil conservation practices. Soil Conservation Review, 12(3), 45-58.

[18] Ravi, S., Breshears, D. D., Huxman, T. E., & D'Odorico, P. (2005). Wind erosion in arid and semi-arid regions. Frontiers in Ecology and the Environment, 3(8), 424-432.

[19] Sharda, V. N., & Dogra, R. K. (2013). Conservation programs and their policy impacts on soil erosion management. Journal of Soil and Water Conservation, 68(6), 485-492.

[20] Sharma, K. D., & Dadhich, S. M. (2018). Wind erosion and sand dune formation in the Thar Desert. Journal of Arid Environments, 150, 1-10.

[21] Van, R. W., et al. (2000). Soil erosion caused by tillage: An overview. Soil Tillage Research, 57(3), 291-302.

[22] Zhang, Y., Wang, L., & Liu, J. (2018). Chemical soil binders in arid regions: Erosion control methods. Environmental Geoscience, 25(4), 312-322.