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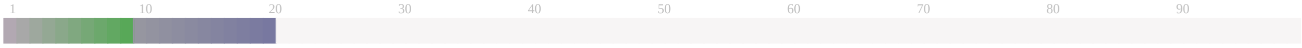

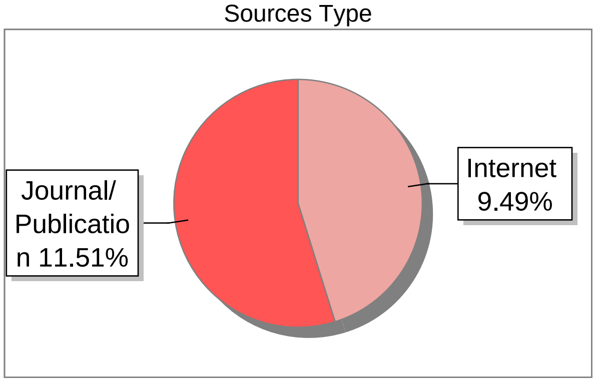

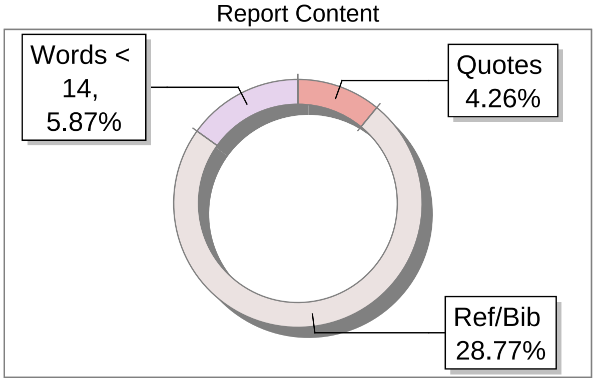

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DEPARTMENT OF CIVIL ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA

A Ph.D. PROPOSAL

ON THESIS TITLED

EVALUATION OF CRUST THICKNESS FORMATION IN SILTY SAND BY MICROBIAL-INDUCED CALCITE PRECIPITATE USING BACILLUS *THURINGIENSIS* FOR WIND-INDUCED EROSION RESISTANCE

BY

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P23EGCV900

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1.0 INTRODUCTION

1.1 General

Wind erosion is a condition in which soil particles move from one abode and deposit at another, is a menace to the environs and leads to several health difficulties (Gao *et al.,* 2023). The ecological problems triggered by wind-induced erosion arise from increasing airborne particulate substance, which lessens reflectivity, low agricultural productivity and leads to air and water contamination (Hao *et al.,* 2021). Arid and sem-iarid regions with sandy soil and minimal rainfall are most prone to these issues (see Plate 1).

a. B. c.

Plate I: Effect of wind: (a) Dust storm (b) Eroded area (c) Dust storm (**Source:** ar.inspiredpencil.com)

A wind tunnel was regulated to simulate the atmospheric boundary layer (ABL) (Gao *et al*., 2023). Wind erosion, in which soil [30] particles move from one place and deposit at another, is a hazard to the environment and leads to many health problems (Hao *et al*., 2021). The environmental issues caused by wind erosion arise from increasing airborne particulate matter, which reduces visibility and leads to air and water pollution (Kangda *et al*., 2023). Dry and semi-arid regions with sandy soil and slight rainfall are most prone to these problems. Creep, saltation, and suspension modes are considered to be the major three modes [18] of wind erosion (see Plate II). Creep transport dominates for soil particles with diameters between 0.8 and 2.0 mm by rolling along the soil surface (Plate II). Saltation dominates [41] for particles with diameters between 0.1 and 0.8 mm; in this mode, a particle jumps along the surface. Finally, suspension dominates for particles with diameters <0.10 mm, and in this mode, a particle is suspended in the air, making nearly no contact with the surface. The transport mode is determined by several factors, including particle density and size and wind velocity (Hao *et al*., 2021).

The forces acting on soil particles subjected to wind erosion consist of aerodynamic drag force (Fd), lift force (FL), inter-particle contact force (Fi), and gravity (Fg) (see Plate II). For soil particles to start eroding, the resultant forces of aerodynamic drag force (Fd) and lift force (FL) must exceed the resisting forces, including the inter-particle contact or bonding force (Fi) and gravity force (Fg) (Devrani *et al*., 2021). Therefore, minimizing wind erosion requires increasing the gravity force or the weight of soil (Fg) and or enhancing inter-particle contact or bonding force

(Fi) that could be achieved using different methods, including MICP, which was the focus of this study (Gao *et al.,* 2023).

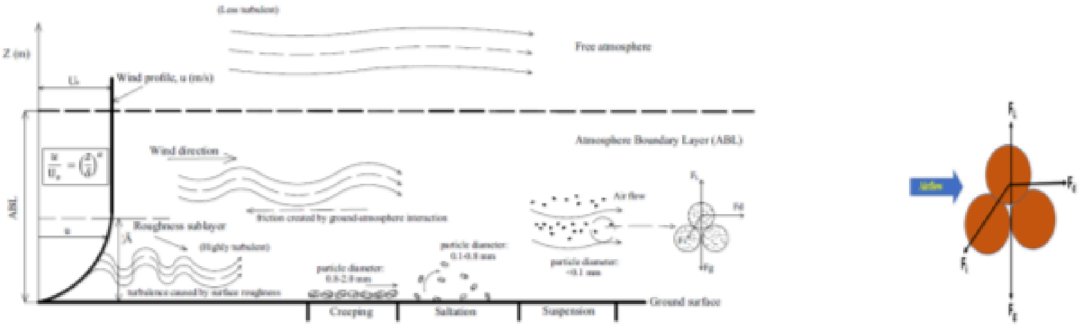

Plate II: (a) Wind erosion transport modes and wind profile near the ground surface (b) Forces acting on a particle resisting on the soil surface under the influence of airstream (*source*: Gao *et al.,* 2023).

Low agricultural productivity is caused by the movement of sand or sand dunes during wind erosion processes by winds moving faster than 5.3 m/s. Over time, this produces dust that obscures the sky, endanger human life and contaminates surface waters and the air. Agronomic and mechanical techniques, as well as chemical sand-fixing techniques, are the main three ways that wind erosion in Aeolian sandy soil is managed (plate IIIa-c) (Devrani *et al*., 2021; Kangda *et al*., 2023). In order to achieve the desired result, the mechanical method involves construction of wind-flow barriers like fences (plate IIIc); the agronomic method uses windbreaks made from harvested crops or living vegetation (plate IIIb); and the chemical sand-fixing method primarily relies on chemical reactions between soil minerals (pozzolanic material) and stabilizer (cementitious material) (plate IIIa). Considering the complex process, unpredicted energy consumption, environmental concerns, and considerable emission of carbondioxide (CO_2) associated with Portland cement (PC) manufacture, researchs on alternatives to cement has been raised (Xiaoniu *et al.,* 2022; Gao *et al*. 2023).

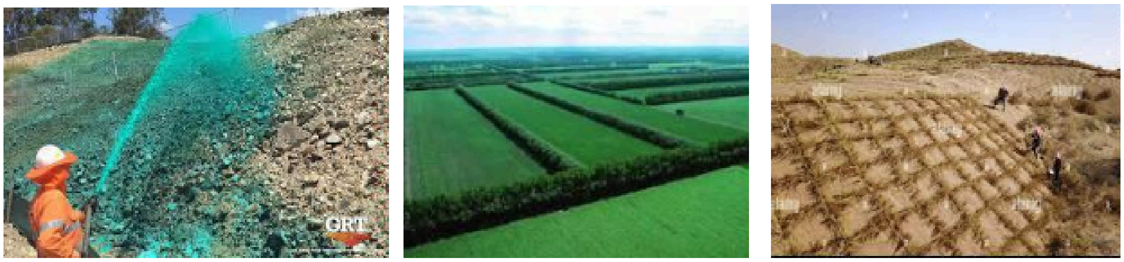

Plate III: (a) Chemical sand-fixing techniques (b) Agronomic techniques (c) Mechanical techniques (source: www.google.com)

Freshly, a fresh soil treatment technique to control wind erosion has been developed. The technique is quite sustainable and environmentally friendly and is used to transform soil behaviour like strength, toughness and penetrability (DeJong *et al*., 2010; Devrani *et al.,* 2021). The method is called Microbial Induced Calcite Precipitation (MICP) and it is a biologically natural method. Urea hydrolyzing bacteria are mostly used in most applications of MICP. The technique is very simple, long-lived, low cost as well as efficient and there is no excess proton production (Whiffin *et al*., 2007; Armstrong *et al.,* 2021). The microbial cement also has many other advantages, such as simple components, easy operation, environmentally friendly, and strong aging resistance (DeJong *et al.,* 2010; Harkes *et al.*, 2010). This allows the microbial cement to be more feasible in dust control.

The bio-product of this process is capable of cementing and binding the soil particles together thereby enhancing firmness as well as reducing the permeability nature of the soil. The technique can be used for old and new structures and has previously been used in stabilization of slopes, sub grade reinforcement and soil liquefaction (Kuan *et al.,* 2023; Sani and Bala, 2021).

1.2 Statement of Problem

A variety of techniques have been suggested for the control and mitigation of wind erosion, such as mechanical methods (Sand hurdles and obstacles), agronomic methods (Shrubbery cover), and chemical sand fixing methods. Nevertheless, these practices have confirmed the limitations of such approaches, such as increasing desertification and build-up of dust-storm in erosion-prone provinces (see Plate I). Soils in arid and semi-arid regions have low cohesion, loose structure, and sparse vegetation cover (Gao *et al.,* 2023). During the dry seasons, high-speed wind can easily detach the exposed surficial soil, resulting in severe problems on agricultural productivity and ecological balance (Hao *et al*., 2021). Furthermore, the particulates suspended in the air feed sandstorms that reduce visibility, contaminate water, and endanger individual health (Hao *et al.,* 2021). The dust storms resulting from wind erosion cause certain health challenges such as asthma outbreaks, bronchitis, and other lung diseases in the air due to the discharge of fine-grained airborne soil particles (Devrani *et al*., 2021; Kangda *et al*., 2023) in the air. To stabilize the soil against wind erosion, surface layer treatments including chemical, oil, and water stabilizers are therefore recommended. Therefore, due to the consideration of the deteriorative health, environmental, and agricultural problems, it is imperative to mitigate wind erosion of desert soil in arid and semi-arid areas. (Dora, 2019; Devrani *et al.* 2020; Sani and Bala, 2021; Hao *et al.,* 2021).

By obstructing the direct path of the wind and the ground, this soil stabilization technique (MICP) can reduce wind erosion (Devrani *et al*., 2021 and Kangda *et al*., 2023). Reducing wind erosion with agronomic techniques, such as growing plants and erecting fencing, is both visually beautiful and less harmful to the environment. Nevertheless, there are certain drawbacks to these two approaches because agronomic techniques cannot be applied to soils that are unsuitable for agriculture (Maleki *et al*., 2016; Devrani *et al*., 2021 and Kangda *et al*., 2023). Furthermore, a

wide range of growth seasons are needed for these techniques, making them inappropriate for use in dry and desert agricultural areas (Hodges and Lingwall, 2019; Tasha *et al.,* 2020).
To reduce wind erosion, the outward coat of silty sand is strengthened using chemical sand fixation techniques and materials (Devrani *et al*., 2021; Kangda *et al*., 2023). These techniques can stop the desert from expanding (Kuan et al., 2023). Cement, sodium silicate, petroleum compounds, and synthetic organic polymer materials are the primary materials utilized in chemical sand fixation; however, using these chemicals has drawbacks, including high cost, aging, short lifespan, and environmental contamination. Chemical sand-fixing has proven to be successful, although the major ingredients in chemical soil hardeners will inevitably contain some hazardous or environmentally unfriendly materials, which could have an impact on the nearby soil (Sojeong *et al*., 2020; Bassey, 2021; Abubakar, 2023). However, mechanical techniques are only able to halt sand dunes' progress momentarily. These steps won't do anything until the sand barriers are buried because sand dunes will always rise. Building and maintaining mechanical methods is expensive, particularly in regions with a shortage of raw resources (Sojeong *et al.,* 2020). Few plant species can withstand the dry climate in desert regions, which places significant restrictions on the application of agronomic techniques. As a result, attempts are being made to find and create possibly environmentally benign, promising procedures that are not just desirable to replace traditional ways.

1.3 Justification for the Study

Microbial induced calcite carbonate precipitation (MICP) is an approach used in geo-technical engineering to enhance soil properties such as improvement of shear strength as well as reduction in soil permeability (Devrani *et al.,* 2020; Minyong *et al.,* 2020). A lot of the studies have been carried out in this area of research (e.g., Lian *et al*., 2018; Osinubi *et al.,* 2017; 2019a, b, c; Gao *et al.,* 2023).

This study is an extension of the earlier researches on the consequence of microbial induced calcite precipitation (MICP) process with regard to wind destruction control in silty sand, especially where vegetation cannot provide sufficient resistance to wind erosion.

1.4 Research Hypothesis

The hypothesis being put forward is that silty sand treated with B. *thuringiensis* using the microbial-induced calcite precipitation (MICP) technique is suitable in mitigation of soil erosion

1.5 Aim and objectives

This research was aimed at the evaluation of wind erosion resistance of Bacillus *thuringiensis* induced calcite precipitation of silty sand. The above aim was achieved through the following objectives:

i. Characterisation of the natural silty sand.

ii. Determination of the effect of B. *thuringiensis* induced calcite precipitate on the physicochemical and index properties of the treated soil.

iii. Evaluation of the strength of the natural and bio-treated Silty sand using pocket penetrometer.

iv. Determine the optimum treatment to cement Silty sand by microbial bio-mineralization.

v. Evaluation of the effect of *B. thuringiensis* induced calcite precipitate on the strength of compacted silty sand (UCS and shear strength).

vi. Evaluation of shear strength parameters of compacted bio-treated silty sand.

vii. Determine the critical threshold wind velocity (TFV) of the natural soil for the most active erosion control.

viii. Determine the soil crust thickness of the optimal bio-treated aeolian at higher wind speed (30 m/s) considered.

ix. Evaluate the erodibility resistance of the bio-treated soil using an experimental wind tunnel chamber

x. Determine the sediment fluxes of the bio-treated silty sands.

xi. Optimization of the results obtained.

1.6 Scope of Study

The study was limited to the laboratory use of B. *thuringiensis* - induced calcite precipitate for the treatment of silty sand in wind erosion control. BS 1377 (1990) and BS 1994 (1990) for natural and treated silty sand will be adopted for all geotechnical procedures carried out while Microbiology Procedures/Guidelines (2010) was adopted for microbiological tests.

2.0 LITERATURE REVIEW

2.1 Background of study

The study of aeolian processes is considered as a sub-discipline by Geomorphologists and geotechnical Engineers that deals with wind erosion. The term Aeolian is obtained from the Greek God Aeolus, the attendant of the winds, so Aeolian practices refer to things created by the power of the wind relating with outward features (Zobeck and Van Pelt, 2015). Transportation of sand or sand dunes during wind erosion processes by wind travelling at speed more than 5.3 m/s results in little agronomic production which in stage produces dust that reduces reflectivity, put humanoid lives in danger and contaminates the air and outward waters. There are basically three methods used to control wind erosion by aeolian sandy soil which are; the mechanical and, agronomic methods and chemical sand-fixing methods (Goudie and Midddleton, 2006). The mechanical method involves the creation of barriers to wind flow such as fences, while agronomic method involves the use of windbreak from the remains of harvested crops or living vegetation, and the chemical sand fixing method relies mostly on chemical reactions among additive (cementitious material) and soil crystals (pozzolanic material) to achieve the required effect.

The bio-product of this process is capable of cementing and clogging the soil particles together thereby enhancing strength as well as reducing permeability properties of the soil.

2.2 Microbial- Induced Calcite Precipitation

There are many advantages attached to the microbial induced calcite precipitation (MICP) research approach. Adequate attention is now given to bio-clogging in order to limit penetration of fluid through the soil or rock pore spaces and bio-cementation so as to strengthen/stiffen the rock or soil medium by microbial action (Osinubi, *et al.,* 2019c; Yohanna *et al*., 2022). Provision of environmentally friendly treatment using less viscous fluid that can infiltrate deeply into the soil or rock stratum, to modify such engineering behaviour of sand (Osinubi *et al.,* 2019d; Abubakar, 2023). Less energy is required, lower cost, less carbon dioxide emission and greenhouse gases, sustainability is one of great task in geotechnical engineering field.

MICP is considered a genuine means of sustainable soil modification (Oliveira, and Neves, 2019). Several researches has reported great observation by researchers, combining geotechnical engineering discipline, biology and microbiology, and certain aspects of chemistry, and rest of the related areas of study for modifying the engineering behaviour of sand. Consequently, the importance of multidisciplinary investigation, that is not limited to geotechnical engineering discipline, has been traced out in the latter period (Osinubi *et al.,* 2019a, Abubakar, 2023).

2.2 Shear strength of Silty sands

The shear strength characteristics of silty sand is designated by its ability to be highly moisture sensitive and hydrophobic in its structure and texture and considerable degree of densification achieved during compaction, the void spaces, particles sizes, stiffness and the stress-strain response of aeolian sand at small, intermediate and large strain level (Salgado *et al.,* 2000; Sojeong *et al.,* 2020). Other variables to determine the shear strength of silty sand, include the relative density of the sand, the effective stress states, and fabric and other factors related to the constitution and general nature of the soil sample such as the particle shape, particle size distribution, particle surface characteristics and mineralogy as well as the intrinsic variables of the sample such as the friction angle, ϕ and cohesion, C of the Silty sand (Armstrong *et. al.,* 2021).

2.3 Soil Stabilization

Soil stabilization entails the different techniques utilized in refining the characteristics of a soil in order to improve the engineering properties of soils (Oliveira, and Neves, 2019).

Soil stabilization involves increasing the soil's strength by modifying its shear strength parameters. Stabilization of soil becomes compulsory when the soil to be used for any construction activity is not of adequate strength to sustenance the planned structural weight (Bassey, 2021).
Generally, soils show unwanted engineering properties. Soil stabilization entails modifying a soil's properties to improve its strength. Stabilization can also be used to progress /or regulate the shrink-swell behaviours of the soil, thus increasing the subgrade's capacity to sustain load from

foundations and pavements. Soil stabilization is also employed to decrease compressibility and permeability of a mass of soil in earth structures (Abubakar, 2023; Bassey, 2021).

Soil stabilization can be classified into two major categories: Mechanical stabilization and Chemical stabilization.

2.3 Wind erosion resistance

The wind erosion test using wind tunnel is conducted to simulate firmness of the outward soil layer induced due to MICP for minimalizing the wind induced erosion.

2.3.1 Threshold friction velocity (TFV)

A key indicator for the risk of wind erosion in dry and semi-arid areas is to evaluate a threshold friction velocity (TFV) during which soil particles begin to migrate, according to Li *et al.* (2010); the TFV is significantly linked to soil properties (Gao *et al.,* 2023). As the most important soil properties affecting TFV have been well established in literature, other factors have been introduced: soil particle size distribution (Van Pelt *et al.,* 2017; Von Holdt *et al.*, 2019); aggregate stability; soil organic matter (Sirjani *et al.,* 2019); and calcium carbonate equivalent (Kouchami-Sardoo *et al*., 2020). In addition to these soil characteristics, researchers also looked at penetration resistance (Kouchami-Sardoo *et al*., 2020; Mina *et al.,* 2020), a measure of the micro-relief of the surface (Kouchami-Sardoo *et al*., 2020) in relation to the TFV. Another important factor in controlling wind erosion is soil crusts which increase likewise the resistance of land surface to shear stress also increase (Mina *et al.*, 2020).

2.4 Optimization

With the increasing growth in the use of science and technology in solving everyday life problems, the need for methods that understand complex and ambiguous problems becomes greatly inevitable. Soft computing is an emerging collection of various methodologies aimed at finding a balance to poor precision, uncertainty, and unclear truth by applying a collection of statistical, probabilistic, and optimization tools in analyzing sets of data, classify the data, identify new patterns, and predict next trends within the shortest convenient time (Onyelowe *et al*., 2023). At the moment soft computing-based techniques are becoming more popular in the field of geotechnics with several works on the application of neural networks and fuzzy logic and little work done on the application of genetic algorithms in this field (Onyelowe *et al*., 2023). Nature Inspired Optimization Algorithms, among the group of nature-inspired optimization algorithms there is Bacteria foraging optimization (BFO), the law of no free lunch (which states that in computational complexity and optimization there is certainly no recognized individual nature inspired optimization technique proficient of resolving all optimization difficulties) was tested by developing two additional algorithms namely, Particle Swarm Optimization (PSO) Algorithm and the Smell Agent Optimization (SAO) Algorithm (Onyelowe *et al*., 2023).

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Soil

The silty sand used in this research will be collected from Daura Local Government Area in Katsina state, Nigeria. The soil was collected from a depth of 15 cm. The soil samples will be transferred to a clean polythene bag and transported to the Soil Mechanics Research Laboratory of the Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

3.1.2 Microorganism

The microbes used in the study is B. *thuringiensis*, which is normally found in soils. The urease positive microbes is rod-shaped, spore-forming and Gram-positive; it was cultured from the soil sample.

3.1.3 Cementation Reagent

The cementation reagent used is composed of 20 g Urea, 10 g NH_4Cl, 3 g Nutrient broth, 2.8 g $CaCl_4$ and 2.12 g $NaHCO_3$ per litre of distilled water, which has been used in several studies (e.g., Stocks-Fischer et al., 1999; DeJong et al., 2006; Al Qabany et al., 2012; Park et al., 2014; Feng et al., 2016; Tirkolaei and Bilsel, 2017). In all the studies mentioned, 3 gL of nutrient broth was added to a cementation reagent because, it was the most effective amount for bacteria survival (Sharma and Ramkrishnan, 2016). However, the arrangement was varied to obtain dissimilar concentrations (i.e., 0.25, 0.5, 0.75 and 1.0 M).

3.2 Methods

Three test procedures using the adopted bacteria (B) – cementation reagent (C) mix ratio (i.e., 25B-75C; 50B-50C; 75B-25C) treatments was used to determine the optimum B. *thuringiensis* nucleation site (i.e., 0, 1.5 x 10^8, 6.0 x 10^8, 1.2 x 10^9, 1.8 x 10^9 and 2.4 x 10^9 cells/ml) and cementation reagent concentration (i.e., 0.25, 0.5, 0.75 and 1.0 M) that gave the best enhancement of the soil properties.

The engineering properties will be determined for the natural and treated laterite soil, through the following tests which will be carried out in accordance to the procedures outlined in BS 1377 (1990) and BS 1924 (1990) for the natural lateritic soil and treated soil, respectively. The following tests will be carried out:

i. Sieve analysis
ii. Atterberg limits
iii. Viscocity
iv. Electrical conductivity
v. pH
vi. Calcium carbonate content (using acid wash method)
vii. X-ray Diffraction Analysis
viii. Compaction (British Standard light (BSL))

ix. Unconfined compression
x. direct shear strength
xi. wind erosion test
  i. soil crust thickness
  ii. *Threshold friction velocity (TFV)*
  iii. *Sediment loss*
  iv. *Sediment flux*
  v. Optimization

In addition to the above tests, statistical analysis of tests results using analysis of variance (ANOVA) as well as micro-structural analysis of the natural and treated soil will be done by Scanning Electron Microscopy (SEM). All test will be done in devotion to BS 1337-2:1990 and ASTM D4 700-15.

3.2.1 Wind tunnel

The wind erosion test was conducted using the wind tunnel (See plate IV). Erosion was simulated using a wind tunnel experimental setup. Wind tunnel setup has a total length (distance between upwind entry and exhaust of the tunnel) of 1.85 m, out of which 0.6 m was a working section. The cross-section dimension of the duct was 0.3 m x 0.3 m (Maleki *et al.,* 2016; Zomorodian *et al.,* 2019).

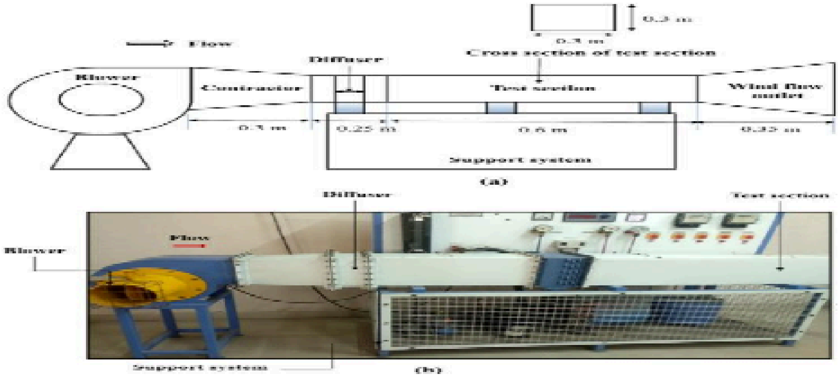

Plate IV: (a) Representation figure of the wind tunnel structure (b) Wind tunnel experimental structure (Source: Monika *et al.,* 2022)

3.2.2 Wind erosion test

The wind erosion test using wind tunnel (plate IV) will be conducted to simulate firmness of the outward soil cover induced due to MICP for minimizing the wind induced erosion.

The weighed Silty sand samples will be placed on pans, prepared and treated in triplicates for each sample bio-treated. The treatment solutions will be injected into the soil sample with the aid of syringe. After the treatment the samples will be left for a period of 24 hours for proper hydration to take place before the introduction of wind load to the bio-treated specimens. In each an every test, the cumulative soil mass loss will be obtained by measuring the soil weight in the pans before and after wind load application. During the test, the soil samples will be subjected to a wind load of 18, 22, 26, 30, 36, 42 and 46 m/s for a period of 60 seconds respectively.

3.2.3 Threshold friction velocity (TFV)

TFV can be obtained by progressively increasing the wind speed in the wind tunnel to grasp the TFV until the advancing movement of the soil particles was observed. (Belnap *et al.,* 2007; Rezaei *et al.,* 2019). TFV determination will be conducted on natural and optimally bio-treated silty sand. This process will be repeated three times to gain the illustrative and precise TFV.

3.2.4. Sediment flux

The sediment flux (qs) is the rate of sediment particles being eroded through a specific area over a particular time. It was calculated using equation (1).

$$\text{Sediment flux, qs (kg/m}^2\text{s)} = [soil\ loss\ x\ (A\ X\ T)] \qquad (1)$$

$$\text{Velocity, V} = \sqrt{2pwgHa/pa} \qquad (2)$$

Where; A = is the area and T = is time taken for the wind load, p = water pressure, g = acceleration due to gravity, Ha = height of the specimen, pa = atmospheric pressure

After bio-treating and mixing, the soil samples with the adopted trial mix ratio for the various microbial suspension densities, will be air-dried before being crushed and passed through BS No. 4 sieve (4.75 mm opening) for use in the wind erosion, the weighed soil samples will be treated in the circular metallic pan and left for 24 hours prior to wind erosion test.

3.3 Optimization

Bacterial foraging optimisation (BFO), particle swarm optimisation (PSO), and smell agent optimisation (SAO) algorithms will be successfully utilized to establish the optimal qs values of the bio-treated soil.

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