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Reducing Particulate Matter Emissions in Landfills Using Novel Dust Suppressants: A New Approach to Improving Air Quality

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Abstract

Climate change is widely recognized as one of the most urgent challenges facing humanity today. It is expected to intensify soil erosion in many regions worldwide, severely impacting ecosystem services, human health, and the environment. This study evaluates dust control strategies using different dust suppressants to understand soil erosion dynamics and develop effective, economical,

and sustainable solutions to improve air quality and public health. Soil samples were collected from the Meyami Landfill Center in Mashhad, a region highly vulnerable to fine dust formation due to its location along wind corridors that carry dust from nearby deserts. In this study, the variables examined include: soil meshes (100, 50, and 20), dust suppressant type (compost, vermicompost, bentonite, and Nano-clay bentonite), suppressant dosage (10, 20, and 30% of soil weight), exposure time (10 and 15 min), and wind speed (4 and 7 m/s). A wind tunnel was used to simulate wind erosion and assess the performance of these suppressants in enhancing soil resistance. Results demonstrated that mesh significantly affects soil erosion, with mesh 20 identified as optimal for all dust suppressants, achieving an efficiency of over 85% in reducing the wind erosion rate. Among the materials tested, compost at a wind speed of 4 m/s, exposure time of 10 minutes, mesh size of 20, and dust suppressant dosage of 10% with an efficiency of 86.52% and bentonite at similar conditions with a dust suppressant dosage of 20% and an efficiency of 80% were the most effective. These findings highlight the potential of these dust suppressants in mitigating soil erosion and improving air quality in vulnerable areas.

Keywords: Air Quality, Dust Suppressants, Landfill, New Approach, Particulate Matter

1. Introduction

Land degradation, as a global challenge, disrupts ecosystem functioning and impairs its capacity to provide environmental services(Eekhout and de Vente, 2022). Climate change impacts are increasingly observable, manifesting as storms, droughts, wildfires, and floods, which in turn exacerbate erosion processes(Rolnick et al., 2022). Furthermore, climate change significantly threatens environmental sustainability and public health, contributing to biodiversity loss(I and N, 2024). Recent studies indicate that such changes may lead to increased dust activity worldwide(Achakulwisut et al., 2019). Variations in the concentration of these particles in the

atmosphere across different regions, including urban areas, depend on multiple parameters such as climatic, environmental, and terrestrial conditions, with climatic factors playing a predominant role in altering pollutant concentrations(rezaei et al., 2024). Population growth and unsustainable exploitation of natural resources in recent decades have accelerated land use degradation, while climate change, through reduced precipitation and rising temperatures, has intensified pressure on ecosystems, resulting in diminished vegetation cover and expanded barren lands. These conditions have fueled the occurrence of dust storms, which themselves reflect land degradation and vegetation loss, and have led to serious economic, social, health, and environmental consequences. Thus, ecosystem changes at the global scale are increasingly driven by a combination of human and natural factors, making an accurate understanding of land use and its dynamics a fundamental prerequisite for the sustainable management of sensitive regions(Norafar et al., 2023).

Extensive research has been conducted to identify climatic factors affecting the concentration of airborne particulate matter in different regions, with each study attributing changes in particle concentrations to various factors(rezaei et al., 2024). For example, a study identified meteorological parameters such as increased wind speed and decreased relative humidity as the most influential factors contributing to elevated PM_{10} concentrations in Xi'an, China(Wang et al., 2015). Similarly, analyses using the dust storm index by Vali and Rostaee have demonstrated that wind erosion in central Iran, particularly in its central and southern areas, has increased significantly in recent years(Vali and Roustaei, 2018). Reduced precipitation, successive droughts, vegetation loss, wetland desiccation, intensified wind erosion, and the absence of long-term planning and investment have further exacerbated dust storms and increased particulate concentrations in the air over most Iranian cities(rezaei et al., 2024). Rising temperatures and declining rainfall are two key drivers intensifying dust storm days. This pattern highlights that dust

storms are characteristic of Iran's hot and arid regions; for instance, the reduction in dust events in southeastern Iran during June is attributed to sporadic seasonal rainfall (Khairoddin, 2020). Iran is situated in an arid climate zone, with over 70 percent of its territory classified as arid or semi-arid, and erosion is recognized as a principal constraint on soil fertility in many regions worldwide, including Iran(Zohrabi S, 2019). In some areas, soil erosion has become a critical societal challenge, with consequences arising from a combination of natural processes and human activities. Various studies have also demonstrated a significant positive relationship between climate variability and soil erosion processes(Pal et al., 2021).

Soil wind erosion is a meteorological phenomenon that occurs when soil or its parent material is lifted into the atmosphere by air currents(Liu et al., 2023). In other words, the process of dissever and displacement of surface soil particles by wind(Xu et al., 2024). Soil particle mobilization takes place only when wind speeds exceed a certain threshold value(Sirjani et al., 2024). These airborne particles can be carried over considerable distances before eventually settling back to the ground (Liu et al., 2023). Soil movement is initiated when the pressure of the wind on the surface soil grains overcomes the force of gravity acting on those grains(Naeimi et al., 2024). Wind erosion significantly contributes to land degradation globally, particularly in arid and semi-arid regions such as Iran. This natural process involves the detachment and movement of soil particles by wind, leading to the loss of fertile topsoil and negatively impacting agricultural productivity(Zhao et al., 2021). Wind erosion generates a significant volume of airborne dust particles, producing approximately 1 to 3 billion tons of dust aerosol annually. This accounts for roughly 30% to 50% of the total global aerosol mass (Chen et al., 2022). Dust aerosol caused by erosion has a significant impact on human health, air quality, ecology, and the climate(Wang et al., 2022). Nevertheless, developing a universal, highly efficient, and cost-effective solution for various types of dust

remains a challenge (Zhou et al., 2018). Recently, the use of polymeric dust suppressants in soil has become one of the innovative and efficient solutions that, in addition to saving water and chemical fertilizers, improve bulk density, reduce water evaporation, increase water infiltration rate in the soil, and decrease risks such as flooding and soil erosion(Barari Shahidani et al., 2024). Furthermore, natural minerals play a positive role in soil protection. The results of soil additives indicate improvements in stability, soil structure, distribution and stability of soil aggregates, and the capacity of soil to supply water(Ji et al., 2022). Research has shown that one of the suggested options to replace chemical fertilizers is the use of compost and vermicompost (Mohabbati et al., 2021). Composting has been widely used as a sustainable approach to managing waste streams and improving and enriching soil(Thomson et al., 2022). Vermicomposting is described as an affordable, sustainable, and rapid method for the efficient utilization of organic waste, involving specific species of earthworms that enhance the conversion of waste into a high-quality final product for agricultural production(Enebe and Erasmus, 2023; Pierre-Louis et al., 2021).

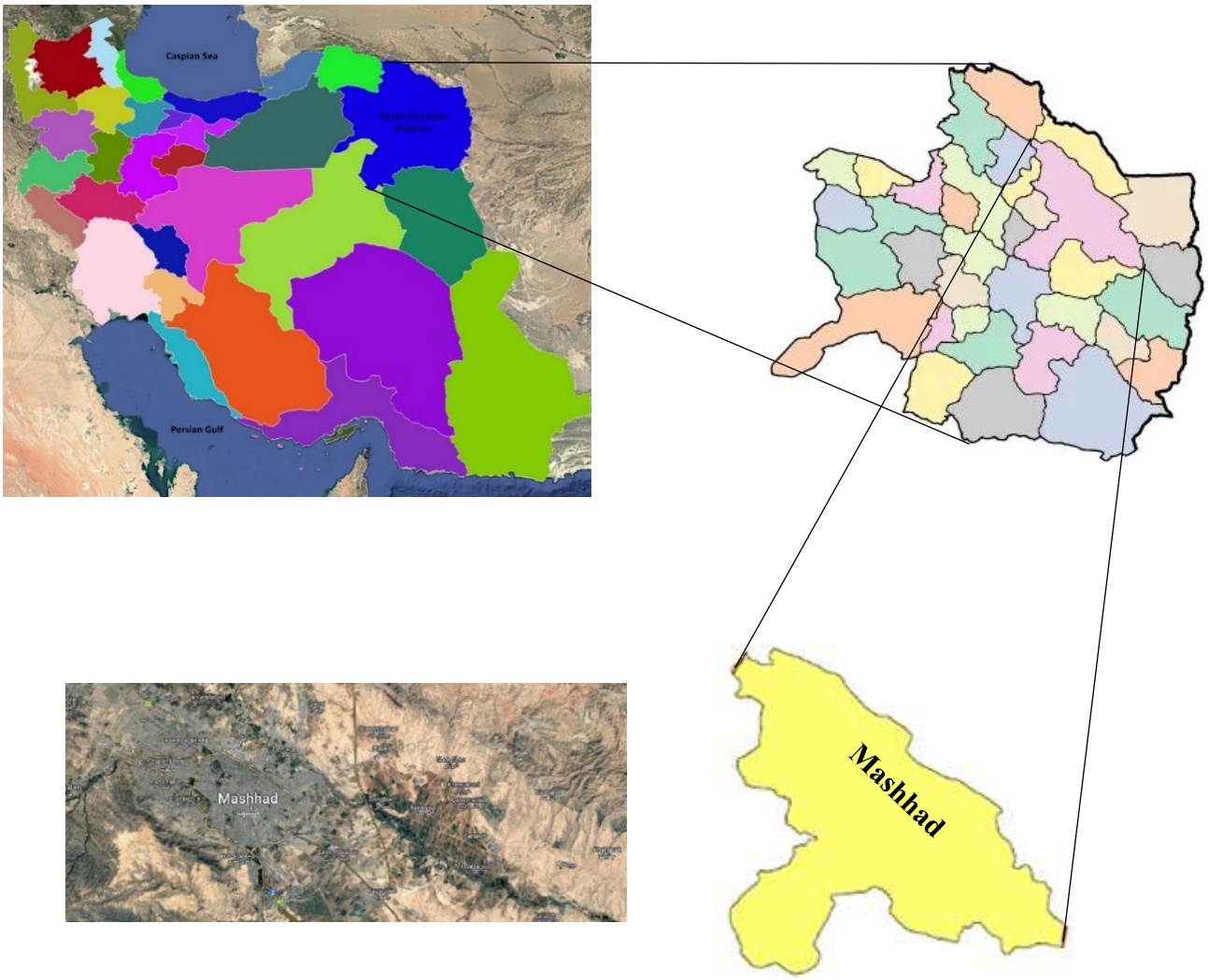
Bentonite clay, as an eco-friendly and non-toxic modifier, can influence the physicochemical properties of soil and has a high capacity for water absorption and retention due to its unique biochemical properties (Costafreda and Martín, 2021). Since most modification methods (such as mechanical methods) are not economically viable, alternative methods with lower costs and greater accessibility were used. The methods mentioned each have their specific advantages and disadvantages, making it challenging to create an efficient yet low-cost system for various types of dust. in this study, we utilized compounds such as compost, vermicompost, bentonite, and Nano-bentonite due to their low cost, environmental friendliness, and soil fertility benefits. Considering that suppressant compounds are readily available, improve and amend the soil, and are environmentally friendly, they were selected for use to investigate their effect as a soil amendment

material on wind erosion. For this purpose, the effect of different variables such as dosage of these dust suppressants, wind speed, exposure time, and mesh of soil was evaluated on the performance of these amendments in controlling soil erosion.

2. Materials and methods

2.1. Study area and sampling

Mashhad is a metropolis in northeastern Iran, serving as the capital of Khorasan Razavi Province. With an area of 351 square kilometers, Mashhad is one of the largest cities in Iran after Tehran. Also, Mashhad, in terms of urban area, falls within the range of medium-sized European cities such as Vienna or smaller metropolises. According to the 2016 general population and housing census, Mashhad has a population of over 3 million people. The city has a variable climate; however, it is generally temperate and tends to be cold and dry, experiencing hot and dry summers as well as cold and humid winters. The maximum temperature in summer reaches 43 ˚C, while the minimum temperature in winter can drop to -22 ˚C(Zayyari and Mansouri Etminan, 2024). Overall, the Mashhad Plain is classified as having an arid to semi-arid climate. The majority of precipitation occurs in late winter and early spring, while the lowest rainfall amounts are observed during the summer season(Golafshani et al., 2021). Since the wind direction in Mashhad is from the southwest and most of the incoming dust comes from the deserts around Mashhad and towards Meyami, the sampling location was selected as Meyami (Fig. 1). Permission to collect soil samples from the study area was obtained through an official letter (No. 11006429, dated 10 September 2024) issued by the Vice Chancellor for Research of Mashhad University of Medical Sciences to the Waste Management Organization of Mashhad Municipality prior to sampling.



a)

b)

Fig. 1. (a) Location of the study area and (b) the sampling area

Landfill No. 2 of Mashhad is located at kilometer 35 of the Mashhad-Meyami Road, after the Charmshahr Industrial Town, within the No. 2 Industrial Recycling Complex. It is recognized as

the largest engineered and sanitary landfill in Iran. The soil studied in this research was obtained from the Meyami landfill and sent to the soil laboratory for grain size analysis and determination of its physical and chemical properties. Samples were taken randomly from areas with fine-grained soil and without suitable vegetation cover, which are prone to dust production. Given the appropriate distance of these points from the city of Mashhad, they can be considered as part of the dust production points in the region. In this study, 10 different locations within the landfill were randomly selected, and samples were taken from the surface to a depth of 15 cm. The samples collected in the laboratory were combined and then sorted. 100, 50, and 20 meshes were used to classify the soil as shown in Fig .2.



Fig 2. Various types of soils with different classifications. a) Mesh 20, b) Mesh 50, c) Mesh 100

2.2. Dust suppressant

To conduct the experiments, four dust suppressants, including compost, vermicompost, Bentonite, and Bentonite Nano Clay, were selected as shown in Fig. 3a and b. Compost and vermicompost were prepared from Mashhad Recycling Complex No. 1. Nano Clay was purchased ready-made from Dr. Mojallalli Company, Iran, and bentonite with an Average particle size of 25 microns and a density ranging from 600 to 1100 kg/m^3 was purchased from Merck through the company Nano SANY Corporation, Iran (Fig. 3c and d). The specifications of the compost and vermicompost

used are presented in Table S1. Bentonite with the formula $Al_2H_2O_{12}Si_4$ and a density of 2.5 g/cm^3 with a high purity grade, appears in colors ranging from cream to brown-grey, with a pH of 6-9, and Nano Clay has the chemical formula $H_2Al_2O_6Si$ and a molecular weight of 180.1 g/mole, exhibiting a light brownish-yellow color white. These dust suppressants were selected for their environmental friendliness, availability, and cost-effectiveness.



Fig 3. Types of dust suppressants used: a) Compost, b) Vermicompost, c) Bentonite, d) Nano Clay

To better correlate the reduction efficiency of dust suppressants in wind erosion rate (WER), a representative soil sample is collected from the study area and subsequently transported to a specialized soil testing laboratory. Within the laboratory setting, various parameters critical for assessing soil quality and condition are measured, among which pH, moisture content, soil texture, and electrical conductivity (EC) are considered paramount. The values corresponding to these parameters are summarized in Table S2.

2.3. Characterization of dust suppressants

To investigate the morphology of the samples and to analyze the size, shape, and surface of the nanoparticles, scanning electron microscopy (SEM VEGA3, TESCAN, Brno, Czech Republic) will be used, along with X-ray diffractometer (XRD PW1730, Philips Co., Netherlands) for analyzing the nanoparticles and their crystallization phases, as well as for identifying and

analyzing the crystalline structure of the materials. Finally, the Fourier Transform Infrared Spectrometer (FTIR Thermo Avatar, Deutschland, Germany) is used to examine functional groups on materials.

2.4. Wind tunnel

To conduct studies on the behavior of dust suppressants and determine their effect on soil resistance against wind erosion, a wind tunnel was designed. A wind tunnel is a key tool for simulating and studying wind erosion of soil under controlled conditions, which helps to understand the processes better and develop effective strategies for erosion control(Jin et al., 2020; Preston et al., 2020; Sieger et al., 2023; Zhou et al., 2018). This wind tunnel consists of two parts. The first section includes a motor and a propeller to generate airflow, along with a wind speed regulator. The height of the motor was adjusted so that the motor axis aligned with the cross-section center of the wind tunnel. To vary the wind speed, an SCR BTA16 inverter (STMicroelectronics NV, Geneva, Switzerland) capable of adjusting the motor speed up to 2800 revolutions per minute was utilized. The second part of the device comprises a test chamber, which is a tunnel measuring 1 meter in length, 15 centimeters in width, and 15 centimeters in height, where the sample is placed. This wind tunnel can simulate wind speeds ranging from a minimum of 3.5 to 13 m/s. A Wintec digital anemometer (WT9056, Shenzhen, China) was used to determine the flow velocity at the beginning and end of the tunnel, as well as at the top and bottom of the tunnel.

2.5. Experimental method

The soil samples were screened through 100, 50, and 20 meshes, respectively, and weighed with an analytical balance to calculate the size distribution of soil particles. In this study, based on the

wind rose diagram of Mashhad city, speeds of 4 and 7 were considered as the minimum and maximum speeds for testing. To investigate the effect of time on the amount of erosion, 10 and 15 minutes were considered. Initially, to investigate the role of soil with varying particle sizes on the rate of wind erosion, each sample was weighed individually without any dust suppressants. The samples were then placed in the wind tunnel tray at a specified speed, and their surfaces were leveled. After a predetermined time, the samples were reweighed. This procedure was subsequently repeated for soil samples mixed with the dust suppressants under defined speed and time conditions. Specifically, the wind speed was adjusted using a dimmer and measured with an anemometer, setting it to 4 meters per second. Subsequently, 100 g of soil sample with a 100 mesh was weighed using a digital scale and placed in a separate beaker (Fig. 4). For the experiments, each dust suppressants were applied to the soil at a rate of 10, 20, and 30% (wt/wt).

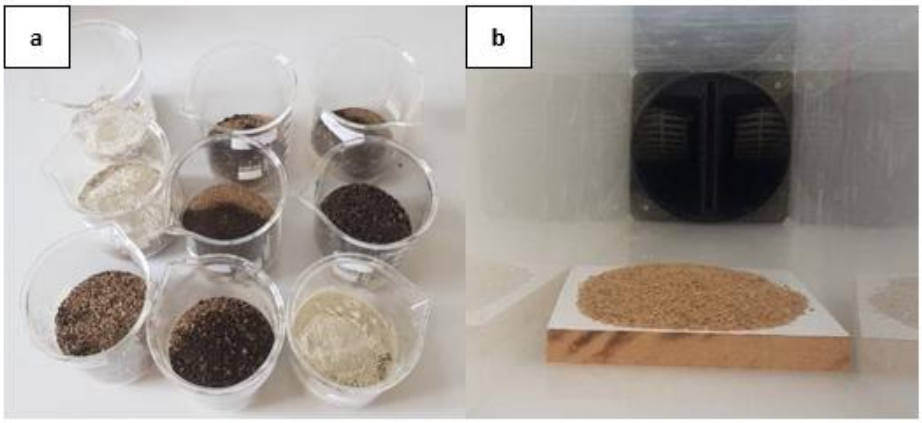


Fig 4. a) Prepared samples, b) sample placed in the wind tunnel

2.6. Wind erosion experiments

To determine the resistance of control and test samples against wind erosion, each sample was placed in a wind tunnel for specified times with varying amounts of dust suppressants at different wind speeds. Initially, tests were conducted at 4 m/s; after completing the tests at this speed, all experiments were repeated at 7 m/s. To determine the amount of eroded soil, each sample was

weighed before and after being placed in the wind tunnel. The difference in weight before and after the wind erosion test indicates the amount of soil eroded during the experiment. In other words, the weight difference in the test samples was compared with the control, and then the efficiency of the dust suppressants in reducing erosion was calculated as follows:

$$\text{Wind erosion rate (WER) (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

$$\text{Reduction in WER (\%)} = \frac{WER_c - WER_t}{WER_c} \times 100 \quad (2)$$

W_i and W_f are the weights of the soil sample before and after the test, respectively. WER_C is the wind erosion rate of control samples; WER_t is the wind erosion rate of test samples.

The selected dust suppressants were added at a rate of 10% (wt) to the soil and mixed thoroughly. After preparing the sample, it was poured onto a flat rectangular surface and positioned in the middle of the wind tunnel. After 10 minutes, Samples were collected from inside the wind tunnel and weighed again. This procedure was conducted for three different soil particle sizes (meshes 100, 50, and 20), using four types of dust suppressants (compost, vermicompost, bentonite, and Bentonite Nano-Clay) at varying dosages (at a rate of 10, 20, and 30% (wt/wt) to the soil) and at wind speeds of 4 and 7 m/s for contact time of 10 and 15 min, as outlined in Table S3.

3. Results & Discussion

3.1. Characterization of dust suppressants

3.1.1. SEM images

SEM images illustrate the structural changes of bentonite at various stages: The Initial structure of bentonite consists of large, layered particles (Fig. S1a). Particle size reduction and increased dispersion are observed after mechanical processing (Fig. S1b-d). The presence of pores on the

particle surface confirms the high adsorption capacity of bentonite. In summary, the presence of a layered structure, particle adhesion, and fine particle size in SEM images of bentonite indicates its high potential for soil erosion control(Laith Saffar Y, 2015). The SEM images of the compost presented in Fig. S1e-h show its surface structure at different magnifications. These images include organic and inorganic materials of various sizes. The observed features include: Numerous pores that confirm the high adsorption capacity of compost (Fig. S1e), Particles of different sizes, resulting from the combination of decomposed organic matter and minerals (Fig. S1f), Layered structures and fractures associated with natural decomposition processes (Fig. S1g and h). Compost, acting as a dynamic and living system, plays a critical role in maintaining soil structure by preventing compaction, improving water infiltration, reducing surface runoff, and consequently enhancing erosion control(Miháliková et al., 2025).

3.1.2. FTIR analysis

The FTIR spectrum indicates the presence of hydroxyl groups, absorbed water molecules, and the silicate-alum inosilicate structure of bentonite, consistent with its mineral and layered nature. The presence of interlayer water and Si–O and Al–OH bonds is also a notable characteristic of bentonite. The FTIR spectrum for compost and bentonite, shown in Fig. 5a, includes specific peaks that refer to the functional groups and mineral structure of this material: peak 3627.62 cm^{-1} corresponds to the stretching vibrations of hydroxyl (-OH) groups in the layered structure of bentonite, such as hydroxyl groups attached to aluminum or magnesium. Peak 3429.86 cm^{1} indicates the stretching vibrations of -OH groups in absorbed water or interlayer water present in the bentonite structure. The peak at 1639.00 cm^{1} refers to the bending vibrations of absorbed water molecules in the bentonite structure. peak 1425.65 cm^{1} may indicate the presence of carbonates or other bending vibrations of organic or mineral groups. Region 1037.94 cm^{1} corresponds to the

stretching vibrations of the Si–O bond in the silicate tetrahedral, which is a primary characteristic of the bentonite structure. Peak 914.87 cm^1 is associated with the bending vibrations of Al–OH groups in the aluminosilicate structure of bentonite. peaks 797.56 cm^{-1} and 698.30 cm^{-1} relate to Si–O–Si or Si–O–Al vibrations, indicating the silicate network of bentonite. Peak of 622.83 cm^1 also refers to the bending vibrations of Si–O or Al–O bonds, and regions 520.05 cm^1 and 468.13 cm^1 typically correspond to the bending vibrations of Si–O or Al–O bonds in the mineral structure of bentonite. The FTIR spectrum of compost indicates the presence of organic compounds such as alkanes, alcohols, and ketones, as well as minerals like silicates. These findings are consistent with the nature of compost, which is a mixture of decomposed organic matter and minerals. The provided FTIR spectrum pertains to compost and includes absorption peaks across various ranges, indicating the presence of different functional groups in the sample. These peaks include: peak 3406.68 cm^1, typically associated with the stretching vibrations of hydroxyl (-OH) groups, which may indicate the presence of water or compounds containing hydroxyl groups such as alcohols and phenols. Peaks 2922.02 cm^{-1} and 2851.98 cm^{-1}, related to the stretching vibrations of C-H bonds in alkanes, are commonly associated with hydrocarbon chains. Peak 1647.54 cm^1, attributed to the stretching vibration of the carbonyl (C=O) bond, which may indicate the presence of ketones, aldehydes, or carboxylic acids. Peak 1425.57 cm^1, corresponding to the bending of CH_2 or CH_3 groups, suggests the presence of organic structures with alkane chains. Peaks 1111.01 cm^{-1} and 1034.36 cm^{-1}, typically associated with the stretching vibrations of C-O bonds in alcohols, ethers, or esters. 874.72 cm^1, 781.63 cm^1, and 673.78 cm^1 are located in the fingerprint region and may indicate bending or torsional vibrations of various groups, such as silicates or minerals. Peaks 604.31 cm^{-1}, 518.50 cm^{-1}, and 470.89 cm^{-1} generally correspond to the bending vibrations of Si-O or Al-O bonds in minerals present in the compost.

3.1.3. XRD analysis

The XRD pattern of compost and bentonite is shown in Fig. 5b. The XRD diagram of compost indicates a relatively amorphous or disordered structure, as there are no sharp and distinct peaks that would suggest a crystalline structure. However, several broad peaks and humps are observed in the diagram, which may indicate the presence of minerals or organic compounds with some degree of order. Specifically, a Broad peak in the range of 20 to 30 degrees (2θ) typically indicates amorphous materials or structures with low crystallinity. In compost, this may be related to the presence of organic materials such as cellulose, hemicellulose, and lignin, which do not have a well-ordered crystalline structure. Sharp peak around 29 degrees (2θ) could indicate the presence of minerals like quartz (SiO_2) or calcite ($CaCO_3$). Peaks in the range of 30-40 degrees (2θ) may correspond to other minerals such as feldspar and mica. However, precise identification requires comparison with standard XRD patterns. As a result, compost is primarily composed of amorphous materials, mainly organic, with the possible presence of minerals like quartz or calcite. The XRD diagram of bentonite shows a crystalline structure with distinct peaks, indicating the presence of minerals with a high degree of order in the structure. Examination of the peaks reveals: Peak around 6 degrees (2θ): related to the interlayer distance d (001) of montmorillonite, indicating the distance between silicate layers in the bentonite structure. The exact position of this peak can vary depending on the type of cations present between the layers and the amount of absorbed water. Peak around 20 degrees (2θ) may correspond to other minerals like quartz, which can exist as impurities in bentonite. Sharp peak around 28 degrees (2θ) is typically related to the mineral quartz, one of the secondary minerals present in bentonite. A Peak around 35 degrees (2θ) could correspond to other minerals such as feldspar or other silicates. In conclusion, bentonite has a crystalline structure and is primarily composed of montmorillonite.

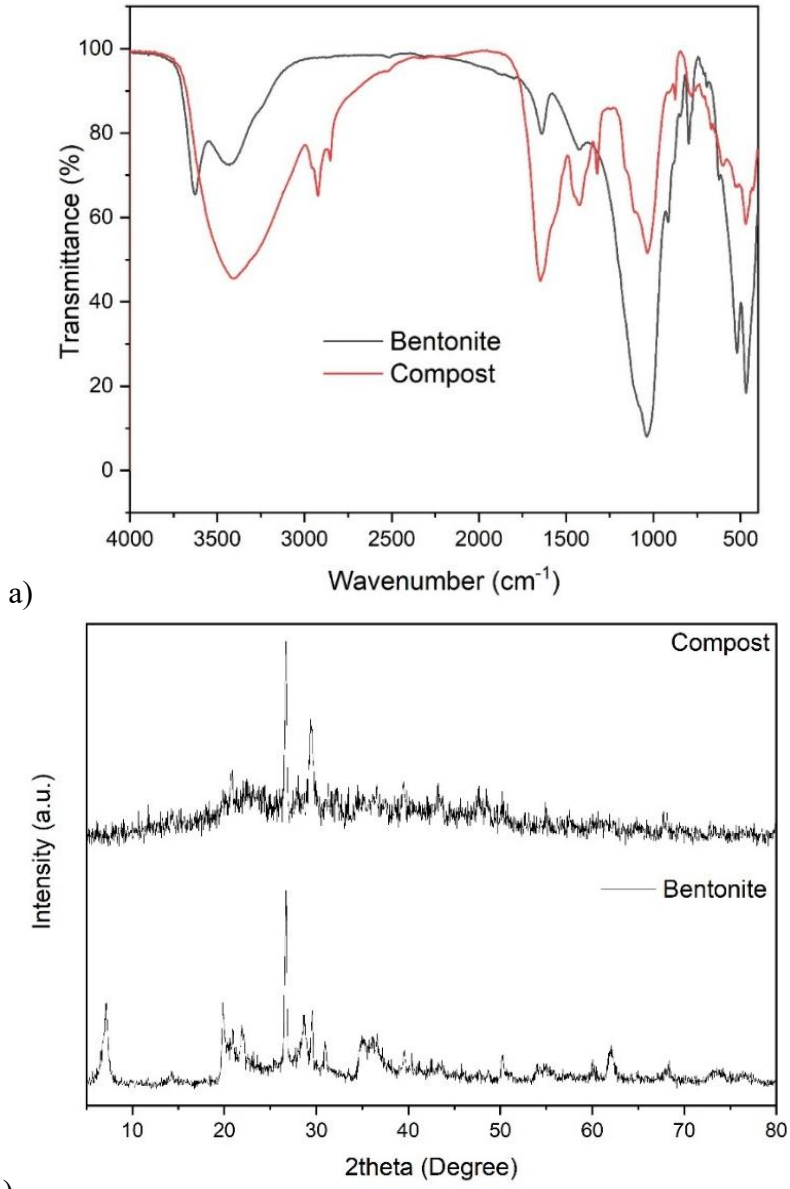


Fig 5. Test results of FTIR (a) and XRD diffraction pattern (b) of Bentonite and Compost

Fig. S2 shows the level of wind erosion in a soil sample before using a dust suppressant. The results indicate a decrease in the weight of soil samples. The figure demonstrates that erosion increases with speed; that is, as speed increases, so does the amount of erosion.

3.2. Effect of soil mesh on soil erosion

Fig. 6 shows the mesh of the soil used in the experiment with Compost, Vermicompost, Bentonite, and bentonite Nano- Clay dust suppressants at speeds of 4 and 7 m/s, indicating that meshing affects soil erosion. For each dust suppressant, different meshes were examined. For example, for compost at different speeds and meshes over a period of 10 min, mesh 20 was found to be the optimal mesh. Similarly, mesh 20 was chosen as the optimal mesh for vermicompost, bentonite, and Nano-Clay bentonite. In this study, 20, 50, and 100 meshes were used for wind erosion tests. Dust suppressants were evaluated at a time of 10 min and speeds of 4 and 7 m/s. Results showed the highest reduction in WER for compost with 100 mesh at 4 m/s was 99.83%, and for 20 mesh at 7 m/s was 89.49% (Fig. 6a). This improvement is attributed to enhanced soil properties due to compost use and the proper bonding between compost and soil due to particle adhesion (Miháliková et al., 2025). Additionally, at higher speeds, the adhesion of soil and dust suppressants decreased, leading to increased WER. For vermicompost as shown in Fig. 6b, the highest reduction in WER was obtained for 20 and 50 mesh at 7 and 4 m/s, respectively. Vermicompost helps control soil erosion due to its physical and chemical properties, which improve soil structure, increase stability by adding organic matter, retain moisture, and prevent water loss(Ho et al., 2022). For bentonite and Nano-bentonite, the highest reduction in WER was for 20 mesh at both 4 and 7 m/s. Bentonite and Nano-bentonite prevent particle separation by creating adhesion between soil particles, reducing erosion, and increasing the ability of soil to retain moisture and nutrients(Mesry et al., 2023). In general, these graphs show that the larger the mesh, the greater the reduction in WER due to the dust suppressant. In other words, there is an inverse relationship between the size of surface soil particles and the intensity of erosion. Larger meshes generally showed a higher efficiency of dust suppressant in WER reduction, likely because they allow larger particles to pass

through, thereby improving porosity and reducing soil erosion(Barari Shahidani et al., 2024). These findings are consistent with the study of Mahmoudabad(Wu et al., 2024).

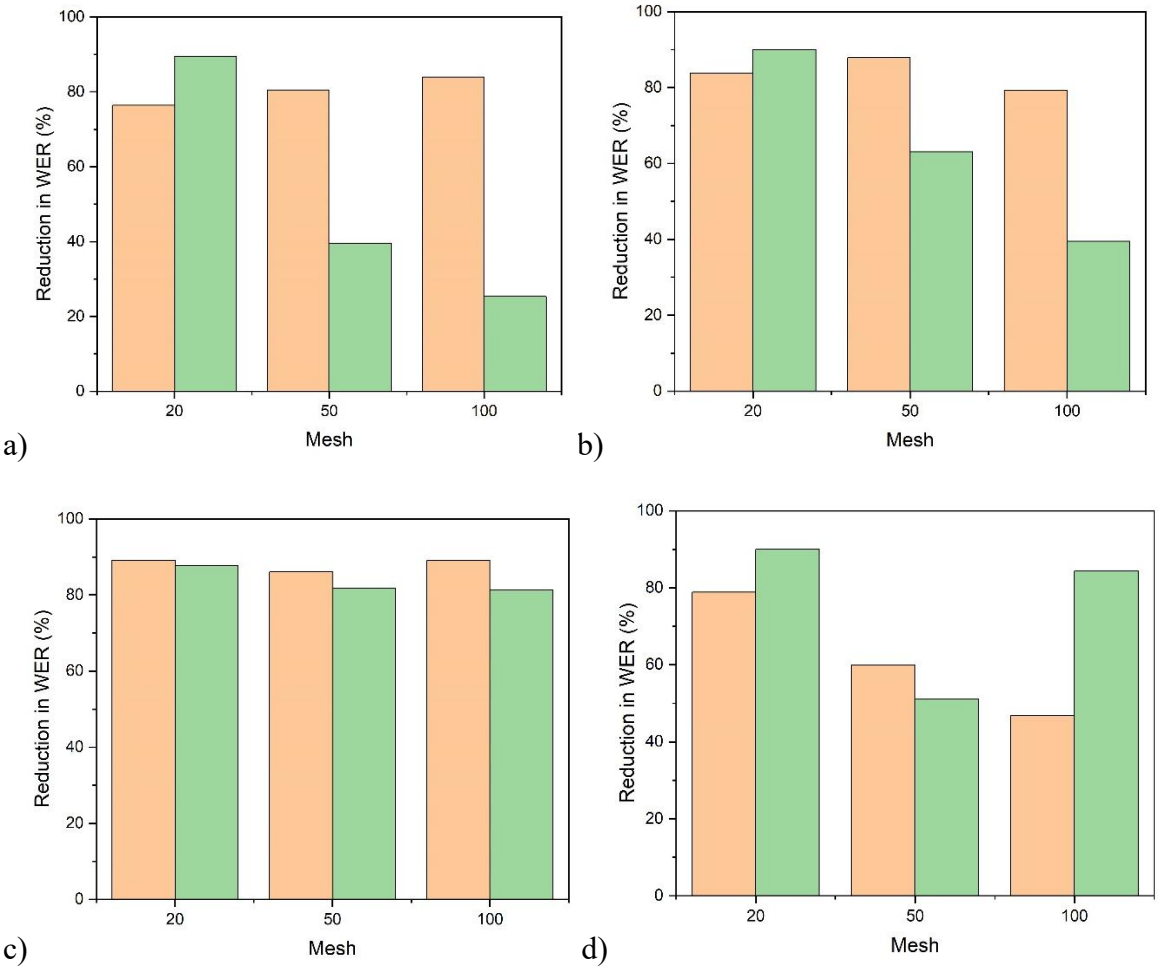


Fig. 6. The effect of meshes on the reduction of WER with different dust suppressants; Time = 10 min, 4 m/s, 7 m/s; a) Compost, b) Vermicompost, c) Bentonite, d) Nano Clay

3.3. Effect of dust suppressant dosage on WER

Fig. 7 illustrates the soil with various meshes and dosages of different dust suppressants used. The dust suppressants were applied at a rate of 10, 20, and 30% (wt/wt) to the soil. The wind erosion rate was investigated at different speeds, and it was found that compost as a dust suppressant has the best efficiency at a 10% wt dosage in reducing WER. Similarly, for the bentonite, vermicompost, and Nano Clay dust suppressants, the best efficiencies in reducing wind erosion

rates were 20, 10, and 30% wt, respectively. In general, the results indicated that all the dust suppressants used significantly reduced soil erosion caused by wind compared to the control group (without dust suppressants). The results of the dust suppressant dosage on WER are shown in Fig. 7 at different speeds and meshes. For compost at speed 4, the highest reduction was achieved at a dosage of 10% for mesh 20 and at dosages of 20% and 30% for mesh 50. At a speed of 7 m/s, the highest reduction was achieved for meshes 50 and 100, with dust suppressant dosages of 10% and 20%, respectively. In Fig. 7b, for vermicompost dust suppressants with a concentration of 10%, the highest reduction for mesh sizes 50 and 20 was observed at speeds of 4 and 7 m/s. The results for bentonite dust suppressants at speeds 4 and 7 m/s were compared in Fig. 7c. It was interesting that for both 4 and 7 m/s, the 20% dosage of the dust suppressants showed the highest reduction for all meshes. The dose of the Nano Clay dust suppressants of 30% showed the highest reduction for speeds of 4 and 7 m/s, as shown in Fig. 7d.

The experimental results showed that all dosages used significantly reduced the WER for all meshes. The experiments showed that the dosage of the dust suppressants has a significant effect on WER. These trends are consistent with existing studies that show soil erosion decreases with increasing dust suppressant concentration until it reaches a constant level (Ding et al., 2018; Lemboye et al., 2021; Owji et al., 2021). On the other hand, the fixed dosages determined only represent the experimental settings and methods of this study and do not necessarily indicate the optimal concentration for field experiments. However, the determined dosages of dust suppressants allow for a comparison of the effectiveness of the dust suppressants used. In all meshes, the results showed that the application of dust suppressants resulted in high dust control effectiveness. Even at low dosage, greater erosion control was observed. This is because the dust suppressant particles are interconnected and prevent the elongation of large molecular bonds (Bao

et al., 2020; Ding et al., 2020). As a result, the density of cross-links increases, and the network space decreases, indicating that low dosages are sufficient for adequate coverage and attachment of the particles to the soil and for bonding with each other against wind erosion(Bao et al., 2020). The results of his study are in agreement with the research of Borughni et. al(Mehdi Boroghani, 2014).

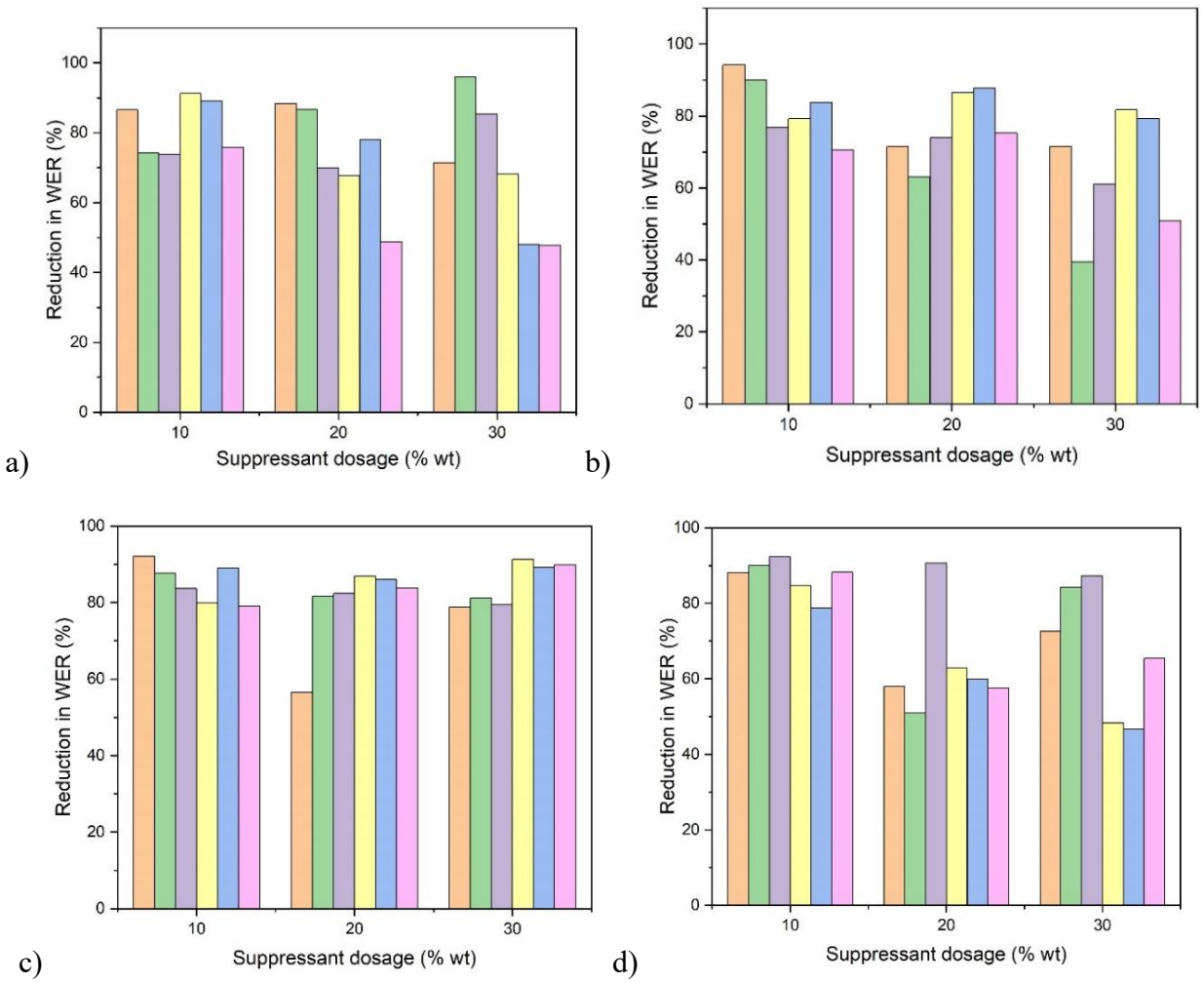


Fig. 7. The effect of different dust suppressant dosages at different wind speeds and soil meshes; a) Compost, b) Vermicompost, c) Bentonite, d) Nano Clay V = 4 m/s, Mesh 20, V = 4 m/s, Mesh 50, V = 4 m/s, Mesh 100, V = 7 m/s, Mesh 20, V = 7 m/s, Mesh 50, V = 7 m/s, Mesh 100

3.4. Effect of time and wind speed on WER

Table 1 illustrates the effect of time on wind erosion rate. Statistical analysis of the results indicated that the time variable does not have a significant relationship with soil erosion (P = .466), meaning that increasing time does not affect the rate of wind erosion. This can be attributed to the small length and width of the wind tunnel, resulting in no significant difference in terms of time. Based on the results obtained in Table 1, 10 minutes was considered the optimal time.

Table 1. Type of dust suppressant with optimal mesh and dosage

parameter	Compost, M20, D10	Vermicompost, M20, D10	Bentonite, M20,D 20	Nano Clay, M20, D30
T=10 min, V= 4 m/s	86.52	79.2	79.14	88.27
T=10 min, V=7 m/s	91.23	94.23	83.74	90.04
T=15 min, V= 4m/s	81.87	79.24	91.11	85.23
T=15 min, V=7 m/s	64.36	75.33	90.51	75.21

M = Mesh, D = Dust suppressant Dosage

Table S4 shows the impact of wind speed on WER. The experimental results at speed of 4 and 7 m/s showed that WER increased with higher velocities in both cases, but this increase was more pronounced at 7 m/s and it is more intense. This can be attributed to the fact that the amount of dust suppressant used is effective in controlling erosion, such that over time, a bond forms between the suppressant and the soil, rendering wind speed ineffective in influencing erosion rates(Kumar et al., 2024). Therefore, a time of 10 min and a speed of 4 m/s were selected as the optimal values.

3.5. Soil Analysis

Based on Table S1, the soil used in the experiments predominantly has a sandy texture, composed of 66% sand, 20% silt, and 14% clay. This composition reduces soil cohesion and increases erosion potential, as sand particles typically exhibit low adhesion and are easily mobilized(Avecilla et al., 2015; Shahabinejad et al., 2019; Vermeire et al., 2005; Zobeck et al., 2013). The soil pH is 7.97,

indicating a neutral range that does not directly affect erosion but provides favorable conditions for biological activity(Avecilla et al., 2015). The electrical conductivity (EC) is relatively high at 6.9 ms/cm, which may indicate the presence of salts affecting soil structure and consistency; elevated EC often promotes soil particle dispersion and exacerbates erosion(Avecilla et al., 2015). Soil moisture is low at 0.93%, and this limited moisture reduces particle adhesion and raises susceptibility to wind and water erosion(Avecilla et al., 2015). The 16.6% thermal conductivity suggests effective heat transfer from the soil surface, potentially influencing drying and evaporation processes(Ayoubi et al., 2022). The low clay content negatively impacts structural cohesion, further intensifying erosion risks(Zhang et al., 2024). Overall, this sandy, low-moisture soil is more vulnerable to erosion unless suitable management practices, such as dust suppressants and moisture enhancement, are employed to mitigate soil loss**.** These materials stabilize soil surface particles, preventing their displacement and dispersion, thereby reducing dust emissions and wind erosion. The application of dust suppressants not only mitigates erosion but also aids in retaining soil moisture and enhancing its biological conditions (Ji et al., 2022; Xu et al., 2025; Zhou et al., 2018). This approach is particularly effective in arid and desert regions, where soils are highly susceptible to erosion. Moreover, dust suppressants strengthen soil structure and prevent surface degradation. When used in conjunction with other management practices such as vegetation cover establishment and moisture control, these materials substantially reduce soil erosion (Bao et al., 2020; Ding et al., 2020; Kumar et al., 2024; Mehdi Boroghani, 2014). Therefore, dust suppressants are key tools for maintaining soil fertility and stability under challenging environmental conditions. Given their positive impacts, widespread adoption of dust suppressants is recommended in erosion control projects.

Conclusion

This study simultaneously examined four types of dust suppressants (compost, vermicompost, bentonite, and Nano-bentonite) on wind erosion from the Meyami Landfill in Mashhad. It also evaluated the effects of various factors such as mesh, suppressant dosage, and wind speed using a wind tunnel, enabling a more precise analysis of suppressant performance. The findings indicate that suppressants perform better at lower dosages, which is significant from both economic and environmental perspectives. Focusing on soil from a region sensitive to wind erosion enhances the practical relevance of the results, and by emphasizing environmental compatibility, the study offers sustainable and optimized solutions for controlling wind erosion. The results indicated that dust suppressants increase soil resistance to wind erosion by forming bonds between the soil and the dust suppressants. Specifically, compost at a wind speed of 4 m/s for 10 minutes with a mesh size of 20 and a dust suppressant dosage of 10% by weight, and bentonite at the same wind speed and duration with a dust suppressant dosage of 20% by weight, were more effective in controlling soil erosion.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Achakulwisut, P., et al. Effects of Increasing Aridity on Ambient Dust and Public Health in the U.S. Southwest Under Climate Change. Geohealth 3, 127-144 (2019).

2. Avecilla, F., Panebianco, J.E., Buschiazzo, D.E.. Variable effects of saltation and soil properties on wind erosion of different textured soils. Aeolian Research 18, 145-153 (2015).

3. Ayoubi, S., Milikian, A., Mosaddeghi, M.R., Zeraatpisheh, M., Zhao, S.. Impacts of Clay Content and Type on Shear Strength and Splash Erosion of Clay–Sand Mixtures. Minerals 12, 1339 (2022).

4. Bao, Q., et al. The preparation of a novel hydrogel based on crosslinked polymers for suppressing coal dusts. Journal of Cleaner Production 249, 119343(2020).

5. Barari Shahidani, Z., Gholami, L., Kavian, A.. Effect of Bentonite Mineral Conditioner on Soil Surface Aggregates Stability. Watershed Management Research 37, 128-143(2024).

6. Chen, W., Meng, H., Song, H., Zheng, H. Progress in Dust Modelling, Global Dust Budgets, and Soil Organic Carbon Dynamics. Land 11, 176(2022).

7. Costafreda, J.L., Martín, D.A Bentonites in Southern Spain. Characterization and Applications. Crystals 11, 706(2021).

8. Ding, X., Xu, G., Kizil, M., Zhou, W., Guo, X. Lignosulfonate Treating Bauxite Residue Dust Pollution: Enhancement of Mechanical Properties and Wind Erosion Behavior. Water, Air, & Soil Pollution 229, 214(2018).

9. Ding, X., Xu, G., Zhou, W., Kuruppu, M. Effect of synthetic and natural polymers on reducing bauxite residue dust pollution. Environmental Technology 41, 556-565(2020).

10. Eekhout, J.P.C., de Vente, J. Global impact of climate change on soil erosion and potential for adaptation through soil conservation. Earth-Science Reviews 226, 103921(2022).

11. Enebe, M.C., Erasmus, M. Vermicomposting technology - A perspective on vermicompost production technologies, limitations and prospects. Journal of Environmental Management 345, 118585(2023).

12. Golafshani, M., Zehtabian, G., Khosravi, H., Malekian, A., Ahmadali, K., Bagheri, S. Desertification early warning based on forecasting of groundwater quantitative and qualitative parameters (Case Study: Mashhad plain aquifer). Irrigation and Water Engineering 11, 382-399(2021).

13. Ho, T.T.K., et al. Compost to improve sustainable soil cultivation and crop productivity. Case Studies in Chemical and Environmental Engineering 6, 100211(2022).

14. I, A., N, S. - Climate Change, Air Pollution, African Dust Impacts on Public Health and Sustainability in Europe. LID - ckae144.1374. Eur J Public Health 34(2024).

15. Ji, B.-y., et al. Effects of different concentrations of super-absorbent polymers on soil structure and hydro-physical properties following continuous wetting and drying cycles. Journal of Integrative Agriculture 21, 3368-3381(2022).

16. Jin, H., et al, Preparation and Characterization of a Composite Dust Suppressant for Coal Mines. Polymers 12, 2942(2020).

17. Khairoddin, S.K.H. An overview of the origin and geographical routing of fine dust and

18. strategies to deal with it in Iran. Application of Geography information system and remote sensing in planning 11, 82-114(2020).

19. 18. Kumar, S., Yadav, B.D., Raj, R. A review on the application of biopolymers (xanthan, agar and guar) for sustainable improvement of soil. Discover Applied Sciences 6, 393(2024).

20. Laith Saffar Y, J.A., Hatfi O. Investigation of the use of bentonite in preventing fine dust and the spread of desertification in soils with sandy loam texture. First International Dust Conference, Ahvaz, Iran(2015).

21. Lemboye, K., Almajed, A., Alnuaim, A., Arab, M., Alshibli, K. Improving sand wind erosion resistance using renewable agriculturally derived biopolymers. Aeolian Research 49, 100663(2021).

22. Liu, Y., et al. Estimates of Dust Emissions and Organic Carbon Losses Induced by Wind Erosion in Farmland Worldwide from 2017 to 2021. Agriculture 13, 781(2023).

23. Mehdi Boroghani, S.K.M., Jalil Vahhabi and Seyed Javad Ahmadi. Investigation of Nanozeolite Effects on Soil Erosion Decreasing using FEL3 Rainfall Simulator. Journal of Watershed Management Research 5, 95-106(2014).

24. Mesry, S., Kiani, F., Ebrahimi, S., Arzanesh, H., Pourmalekshah, A. Effect of Compost and Vermicompost on Some Soil Characteristics and Runoff and Sediment Changes. Journal of Watershed Management Research 14, 103-114(2023).

25. Miháliková, M., Báťková, K., Dvořák, P., Kara, S.R., Almaz, C., Král, M., Badalíková, B., Hejátková, K., Mašán, V., Burg, P., Plíva, P. Effect of surface-applied compost on soil properties. Soil and Water Research 20, 71-83(2025).

26. Mohabbati, N., Gholami, L., Kavian, A., Shokrian, F. Effect of Compost and Zeolite at Various Time Periods on Amount of Soil Splash. Journal of Water and Soil Conservation 28, 207-224(2021).

27. Naeimi, M., Shobeirian, F.S., Haddad, A. Olivin geopolymer as a potential green sustainable dust control. E3S Web Conf. 575, 07004(2024).

28. Norafar, A., Gholami, H., Moradi, N., Rahdari, V., Rezaei, M. Investigating the Effects of Land Use Changes on Dust Storms in the Sistan Region Using Markov Chain Forecasting. Desert Management 11, 1-16(2023).

29. Owji, R., Habibagahi, G., Nikooee, E., Afzali, S.F. Wind erosion control using carboxymethyl cellulose: From sand bombardment performance to microfabric analysis. Aeolian Research 50, 100696(2021).

30. Pal, S.C., Chakrabortty, R., Roy, P., Chowdhuri, I., Das, B., Saha, A., Shit, M. Changing climate and land use of 21st century influences soil erosion in India. Gondwana Research 94, 164-185(2021).

31. Pierre-Louis, R.C., Kader, M.A., Desai, N.M., John, E.H. Potentiality of Vermicomposting in the South Pacific Island Countries: A Review. Agriculture 11, 876(2021).

32. Preston, C.A., McKenna Neuman, C., Boulton, J.W. A wind tunnel and field evaluation of various dust suppressants. Journal of the Air & Waste Management Association 70, 915-931(2020).

33. rezaei, H., Moradi, M., Haji Agha Nezhad, Y. Investigation of the effect of climatic parameters on the change of concentration of suspended particles less than 10 micrometers in Zabol city and its relationship with military health. MILITARY MANAGEMENT QUARTERLY 23, 79-98(2024).

34. Rolnick, D., et al. Tackling Climate Change with Machine Learning. ACM Comput. Surv. 55, Article 42(2022).

35. Shahabinejad, N., Mahmoodabadi, M., Jalalian, A., Chavoshi, E. In situ field measurement of wind erosion and threshold velocity in relation to soil properties in arid and semiarid environments. Environmental Earth Sciences 78, 501(2019).

36. Sieger, J.L., Lottermoser, B.G., Freer, J. Effectiveness of Protein and Polysaccharide Biopolymers as Dust Suppressants on Mine Soils: Results from Wind Tunnel and Penetrometer Testing. Applied Sciences 13, 4158(2023).

37. Sirjani, E., Sameni, A., Mahmoodabadi, M., Akbar Moosavi, A., Laurent, B. In-situ wind tunnel experiments to investigate soil erodibility, soil fractionation and wind-blown sediment of semi-arid and arid calcareous soils. CATENA 241, 108011(2024.)

38. Thomson, A., Price, G.W., Arnold, P., Dixon, M., Graham, T. Review of the potential for recycling CO2 from organic waste composting into plant production under controlled environment agriculture. Journal of Cleaner Production 333, 130051(2022).

39. Vali, A., Roustaei, F. Investigation of the Wind Erosion Trend in Central Iran using Dust Storm Index in the Last Fifty Years. Journal of Water and Soil Science 21, 189-200(2018).

40. Vermeire, L.T., Wester, D.B., Mitchell, R.B., Fuhlendorf, S.D.Fire and Grazing Effects on Wind Erosion, Soil Water Content, and Soil Temperature. Journal of Environmental Quality 34, 1559-1565(2005).

41. Wang, P., et al, C. Impact of Meteorological Parameters and Gaseous Pollutants on PM2.5 and PM10 Mass Concentrations during 2010 in Xi'an, China. Aerosol and Air Quality Research 15, 1844-1854(2015).

42. Wang, X., Zhao, W., Liu, S., An, Y., Pereira, P. Ecosystems impact on aeolian dust emissions in Inner Mongolia from 2001 to 2018. Geoderma 422, 115938(2022).

43. Wu, X., Wang, S., Cheng, H., Yang, Y. Variation of soil organic matter with particle size in the wind erosion region of northern China. CATENA 241, 108025(2024).

44. Xu, H., et al. Enhanced assessment of regional impacts from wind erosion by integrating particle size. CATENA 239, 107937(2024).

45. Xu, Y., et al. A sustainable dust suppressant derived from agricultural straw: Mechanisms, performance, and environmental impacts. Results in Engineering 27, 105873(2025).

46. Zayyari, K.A., Mansouri Etminan, A. Formulating a Framework for Assessing Urban Resilience for Water Insecurities. Geography and Urban Space Development 11, 45-64(2024).

47. Zhang, S., et al. Preparation, characterization, and synergistic soil moisture retention effects of a by-product-based dust suppressant for fugitive dust suppression. Atmospheric Pollution Research 15, 102004(2024).

48. Zhao, C., et al. Impacts of climate change on wind erosion in Southern Africa between 1991 and 2015. Land Degradation & Development 32, 2169-2182(2021.)

49. Zhou, L., et al. Evaluating of the performance of a composite wetting dust suppressant on lignite dust. Powder Technology 339, 882-893(2018).

50. Zobeck, T.M., Baddock, M., Scott Van Pelt, R., Tatarko, J., Acosta-Martinez, V. Soil property effects on wind erosion of organic soils. Aeolian Research 10, 43-51(2013).

51. Zohrabi S, K.H., Mesbahzadeh T, Jafari M, Dasturani M. Investigation of the threshold speed of wind erosion and its influence on soil characteristics in dust production centers of Alborz province. Geographical Studies of Arid Regions 30, 1-3(2019).

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