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Effect of $CaCl_2$ and $MgCl_2$ Solution Mulching on Sand Harvesting in Wind Erosion

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ABSTRACT

Wind erosion is a significant issue that causes severe damage to natural areas in arid and desert regions. Natural and biological mulches play a crucial role in stabilizing dunes and lands affected by wind erosion. One such option is a natural mulch derived from a solution extracted from the Khour Playa containing $CaCl_2$ and $MgCl_2$. In this study, trays filled with sand samples from Mesr village were used to assess the potential for sand harvest and transport by wind flow in a tunnel. Mulching was applied using solutions at concentrations of 5%, 10%, 20%, 40%, 80%, and 100%. Sand harvesting was measured at various wind speeds (0-25 m/s) over different time intervals. The results of the analysis of variance, based on a completely randomized design (CRD), and mean comparisons indicated that this solution effectively prevents sand movement. Therefore, this mulch is highly suitable due to its minimal negative effects and lower cost compared to alternative oil mulches. Applying a rate of 2.5 liters per square meter of the stabilizing $CaCl_2$ and $MgCl_2$ solution in a natural environment on active sand fields can help stabilize the sands, create a suitable protective layer thickness, and withstand erosion from particle impact for at least one year.

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1. Introduction

Desertification, as an environmental problem, currently plagues many regions of the world, resulting in the loss of renewable resources (Ahmadi, 2004). It is a process driven by both natural factors and improper human actions (Reynolds, 2008). Soil erosion is one of the most fundamental consequences of desertification and land degradation, causing destructive ecological changes in many arid and semi-arid lands. Its increasing rate is considered a threat to natural resources, agriculture, and the environment (Rahman *et al*., 2009). Over 90% of Iran's 165 million-hectare area consists of the Iranian plateau, of which approximately 3.7 million hectares are saline and desert areas (Jafari, 2000). Most of these areas are located in Iran's central watersheds, which comprise deserts and plains covered with flowing sands, extensive alluvial fans, and isolated mountains (Krinsley, 1970). Wind has covered 25% of the planet's desert surfaces with sand and moves tens of millions of tons of soil annually. On the Earth's surface, desert winds can transport more sediment in cubic meters per year per kilometer of width than any other geomorphological phenomenon (Rivandi *et al*., 2013). Wind erosion involves the harvest, transport, and deposition of soil materials by wind. In areas without cover or with very sparse vegetation, particularly vast desert lands, wind can move large quantities of material (Refahi, 2009). The solution to combat this phenomenon is to reduce wind speed, increase cover, and enhance soil resistance against erosive winds (Rezaei, 2009).

Over the past fifty years, researchers have evaluated various stabilizers to identify suitable materials and methods for controlling wind erosion. Diouf *et al*. (1990) found that the resistance of surface crust to abrasion increases with a higher clay content. Adding 10 to 20 grams of bentonite clay per kilogram of sand reduced soil erosion by 20 to 30 times compared to the control. Charman and Murphy (2000) noted that clay generally decreases soil erodibility, while the calcium cation helps flocculate soil colloids and reduce erodibility. Ahmadi and Ekhtesasi (2000) studied the impact of gravel mulch on reducing wind erosion in clay lands and found that a 50% gravel cover can effectively protect the land surface. Majdi *et al*. (2006) investigated the effect of combined clay, sand, and straw mulch on stabilizing flowing sands, suggesting that increasing mulch thickness and adding straw can enhance resistance to wind erosion. Additionally, research on the use of Nucleos (M19) polymer mulch in controlling wind erosion in the Segzi Plain showed that this polymer improves water retention capacity, increases soil surface and compressive strength, and reduces dust production (Heidari Morche Khorti *et al*., 2023).

Zare *et al*. (2023) found that the levels of nitrogen (N_2), calcium sulfate ($CaSO_4 \cdot 2H_2O$), phosphorus (P), calcium (Cl), and organic matter (%OM) in the wind-blown sediments studied did not differ significantly before and after mulching ($P>0.01$). Sodium and magnesium concentrations at a depth of 10-20 cm also did not show a significant change. However, salinity and alkalinity increased significantly after mulching ($P<0.01$). Salinity levels at different depths increased by 295.9% and 255.7% with and without mulching at the first depth, 173.7% at the second depth, and 42.3% at the third depth. Alkalinity increased at different depths by 97.9% and 56.8% with and without mulch at the first depth, 36.7% at the second depth, and 92.5% at the third depth. Due to the negative impact of mineral mulch on certain characteristics of wind-blown sediments and the promotion of physiological dryness, the use of this type of mulch is not recommended for stabilizing quicksand and combating dust.

Akbarian and Moradi (2025) conducted a study on the impact of petroleum mulch on heavy metal concentrations in coastal dunes in eastern Hormozgan province. They found that while mulch can increase heavy metal concentrations in the soil due to petroleum compounds containing these elements, it may become an environmental pollutant if heavy metal levels exceed standard limits. The study's results provide valuable insights, but further research is needed for decision-making by relevant authorities on the use or abandonment of oil mulch.

In a separate study, Abtahi and Khosroshahi (2023) evaluated various methods to combat wind erosion in desert areas, focusing on the Kashan desert. Their findings indicated that 50% sand spraying combined with 100% stabilization was the most effective method for stabilizing loose sands and ensuring stability and sustainability. The cost of implementing this method per hectare was significantly lower than that of wooden windbreaks and net windbreaks, making it the most cost-effective and environmentally friendly erosion prevention method.

One of the main sources of salt production in Iran is its playas. The resulting brine contains various salts, with NaCl being the main salt found in central Iran. The high evaporation rate in the desert region, coupled with low rainfall, has allowed the Potash Khour company (affiliated with the Iran Minerals Production and Supply Company) to concentrate the brine from the Khour and Biabank playas in solar evaporation ponds. This process helps in depositing salt and extracting Carnallite, the primary potash material used in the factory. After the extraction of salt and Carnallite, a small percentage of the remaining playa brine, known as final brine or DC400, contains a mixture of calcium and magnesium chloride. With a density of 1.54 g/cm³, DC400 is used as a stabilizer, similar to other petroleum and chemical mulches, due to its hardening and moisture-absorbent properties.

This research aims to study the impact of DC400 soluble mineral mulch on sand erosion by conducting experiments in a wind tunnel.

2. Materials and Methods

2.1. Experimental Site and Treatment Details

The Mesr region in Khour and Biabank cities of Isfahan province is situated in the central desert basin of Iran, southwest of the Great Salt Desert (Desert Plain). It lies between 33°37' to 34°11' north latitude and 54°16' to 55°14' east longitude. The climate in this region, based on data from the Khour and Biabank synoptic station and analyzed using the DeMarton and Ghosen methods, is characterized as hot, dry, and desert-like. The absolute minimum temperature recorded in the region is -14°C, while the absolute maximum is 47°C. The average annual rainfall at Khour and Biabank stations is 86.3 mm. The predominant vegetation in the area consists of *Artemisia sieberi* and *Zygophyllum atriplicoides*. However, factors such as dunes, playas, salt marshes, and human activities have led to a significant portion of the region being devoid of vegetation due to severe limitations imposed by soil salinity and alkalinity. Across all land and soil types in the region, a classic surface horizon is present based on the established plant types.

Half a ton of sand was collected randomly from various dunes in the western part of Mesr and Farahzad Village and transported to the laboratory by van. Upon arrival, the sand was thoroughly mixed using shovels before being filled into wind tunnel trays.

The wind tunnel used in this research is model WT-PI 92/1, jointly produced by the Potash Company and the International Desert Research Center (IDRC). It is a free-flow type, equipped with a three-phase electric motor running at 2400 revolutions per minute, a propeller diameter of 60 cm, and a metal body measuring 3 x 0.3 x 0.3 m. The tunnel is capable of producing wind flows at speeds ranging from 2.5 m/s to 25 m/s. A schematic of the tunnel is shown in Figure 2. The trays used in the wind tunnel are standard test plates with dimensions of 25x100 cm and a depth of 4 cm. These experimental trays were placed inside the wind tunnel. In the first step of the test, trays were filled with sand to assess the potential for sand harvesting through tunnel wind flow. Five replicates were used to measure erosion and the amount of sand transported at different wind speeds ranging from 0 to 25 m/s(0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, and 25 m/s). Various time intervals were implemented for each speed based on the quantity of sand collected.

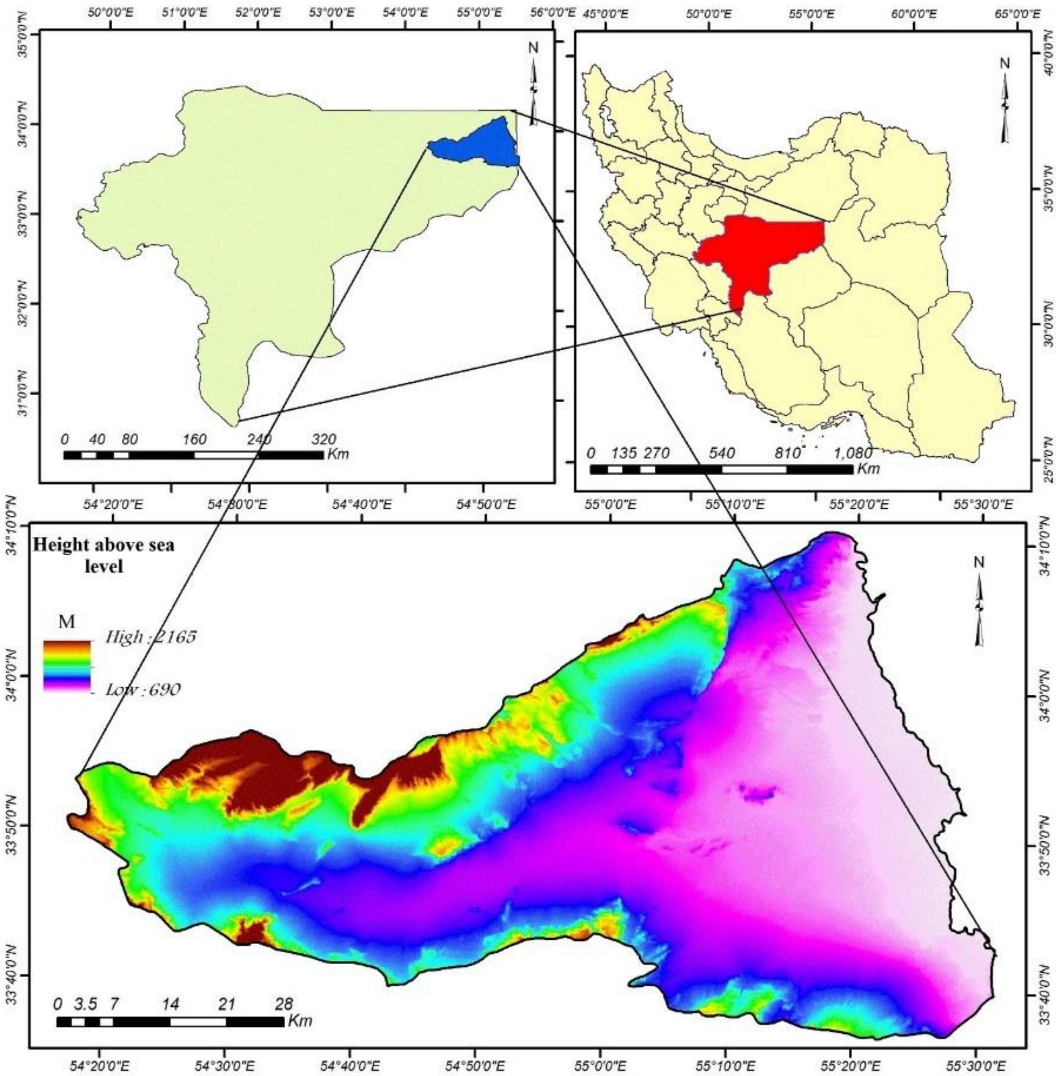

Figure 1. Geographical location of the study area

The mulch used in this study is the effluent from the solar evaporation ponds of the potash production unit, containing stabilized calcium chloride and magnesium chloride solution. The treatments included a control (no solution) and application rates of 0.312, 0.625, 1.25, and 2.5 liters per square meter of the solution. The solutions were sprayed onto sample trays using a sprayer pump. Each treatment was replicated three times and exposed to sunlight for 48 hours after spraying.

The investigated treatments were exposed to a wind flow with a speed of 20 meters per second (equivalent to 72 kilometers per hour in the central part of the tunnel) for a duration of 30 minutes. The amount of sand transported from the test trays was collected in a bag and weighed using a sensitive scale.

At the end of the experiment, the data were evaluated for normality using the Kolmogorov-Smirnov test and checked for homogeneity of variances. Subsequently, the data were analyzed using analysis of variance (ANOVA) in a completely randomized design, and mean comparisons were performed using Duncan's multiple range test. The tests were conducted using SPSS software, version 20.

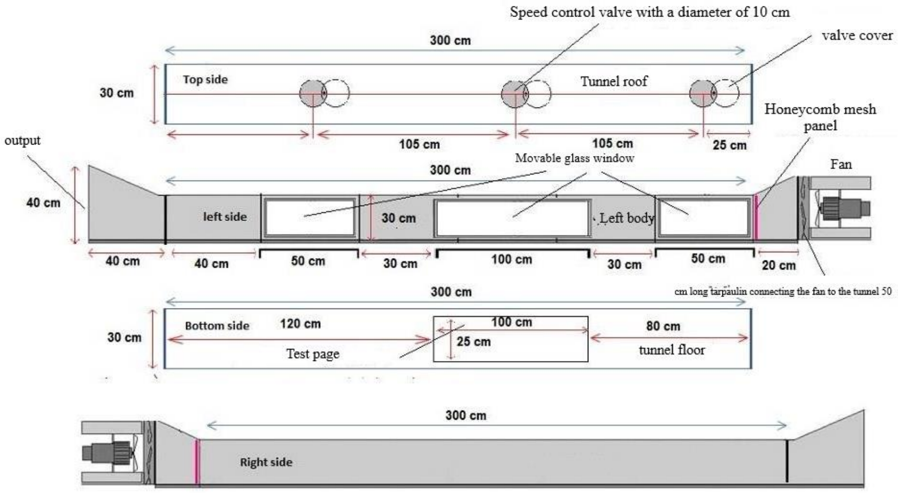

Figure 2. Wind tunnel schematic for experimental design

3. Results and Discussion

The study examined the potential for sand harvesting at various wind speeds, and the results are presented in Table 1. The data indicate a significant increase in sand extraction at a wind speed of 12.5 m/s. Therefore, any proposed solution must be capable of retaining the sand at this speed to be considered an effective mulch.

Table 1. Amount of sand harvesting at different speeds in the wind tunnel used in the research

Speed (m/s)	Repetition 1	Repetition 2	Repetition 3	Repetition 4	Repetition 5	Average ($Kg/m^2/h$)
2.5	00.000	00.000	00.000	00.000	00.000	00.000
5.0	00.000	00.000	00.000	00.000	00.000	00.000
7.5	0.288	0.112	0.214	0.120	0.125	0.200
10.0	0.980	0.620	0.300	0.165	0.650	0.500
12.5	12.300	25.360	13.500	11.230	9.360	14.350
15.0	23.800	88.800	63.600	100.800	70.200	69.400
17.5	88.300	123.100	91.800	116.700	98.300	103.600
20.0	184.200	208.200	164.800	145.900	156.200	171.900
22.5	248.400	240.500	199.500	220.500	235.100	228.800
25.0	289.100	245.500	287.200	266.100	281.300	273.200

The effectiveness of the combined solution in stabilizing sand was evaluated by measuring the amount of sand harvested from the surface of test trays treated with mulch at various concentrations. The results of the five treatments conducted inside the tunnel at a speed of 20 m/s are presented in Table 2.

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A comparison of mean sand extraction was conducted using Duncan's method, and the results are shown in Figure 4. The mean comparison results indicate that spraying 0.312 liters of the combined calcium and magnesium chloride solution per square meter can significantly inhibit sand movement at a speed of 20 m/s under wind influence. Only the control treatment exhibited significant erosion amounts and was placed in the first group.

Table 2. Sand harvesting values under wind flow at 20 m/s for the investigated treatments

Treatment number	Amount of solution (Lit/m^2)	Repetition	Sand extraction rate (Kg/m^2/h)	Average harvest (Kg/m^2/h)
1	0.000	1	182.300	173.500
		2	164.800	
		3	145.500	
2	0.312	1	0.221	0.193
		2	0.164	
		3	0.195	
3	0.625	1	0.053	0.017
		2	0.000	
		3	0.000	
4	1.250	1	0.000	0.000
		2	0.000	
		3	0.000	
5	2.500	1	0.000	0.000
		2	0.000	
		3	0.000	

| Treatment Number | Amount of Solution (Lit/m²) | Repetition | Sand extraction rate (Kg/m²/hr) | Average harvest (Kg/m²/hr) ||

Table 3. Analysis of variance of erosion values for investigated treatments under wind flow influence

	Sum of squares	Degree of Freedom	Mean square	F
between groups	31.49	4	7.12	65.137**
Inside the groups	66.90	10	56.90	
total	97.50	14		

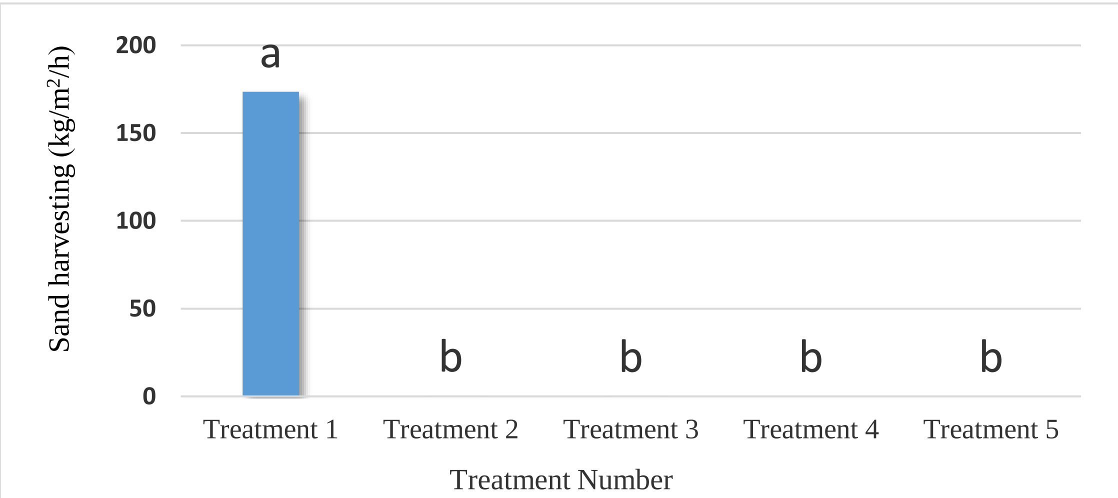

Figure 4. Results of the grouping of average sand harvesting in the investigated treatments using Duncan's method

All treatments with the solution reduced the amount of sand harvesting (i.e., erosion) and showed efficiency in controlling sand movement under tunnel conditions, placing them in the second group (Figure 5).

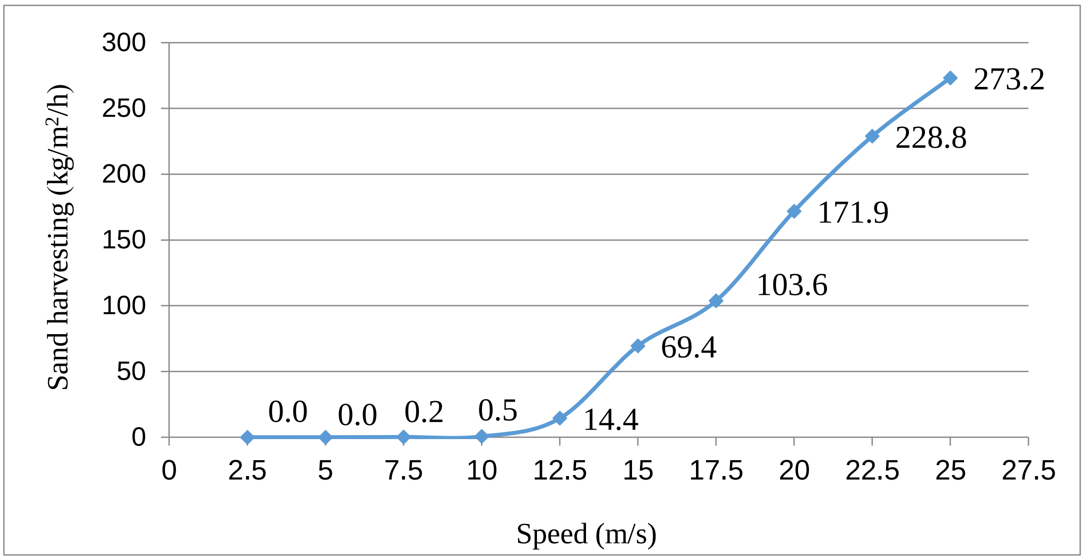

Figure 5. Estimation of sand harvesting rate at different speeds using a wind tunnel

Based on the research data, a second-degree exponential relationship with a coefficient of determination (R^2) of 98% was identified between wind speed and the amount of sand harvested, as represented by Equation 1.

Equation 1:

$y = 0.774X^2 - 8.479X + 16.526$

$R^2 = 0.98$

In this equation, y represents sand harvesting and x represents wind speed in the tunnel.

4. Conclusion

With 60 different playas in Iran, mainly located in the central, eastern, and southern regions of the country (Ahmadi, 2022), it is feasible to extract and produce the combined solution of DC400 from desert stream sources, particularly Khour and Biabank playas (Mousavi *et al.*, 2016). Khour and Biabank playas in the Great Salt Desert of Iran were selected for this purpose due to their high KCl levels in brine, large salt crust size and thickness, ample brine storage, accessibility to sub-crustal waters, easy access, proximity to urban areas, pre-existing access roads, and economic-social considerations (Mousavi *et al.*, 2016).

The investigation into the effect of spraying a combined calcium and magnesium chloride solution, both in laboratory settings, has shown that this substance can effectively reduce erosion and prevent the movement of sand particles at speeds up to 20 m/s. In natural conditions without any mulch, this speed can transport thousands of tons of sand per year, leading to destructive consequences. Some polymer-based mulches, such as butadiene-styrene (Siddiqi and Moore, 1981) and polyvinyl acetate polymer (Movahedan *et al.*, 2009), have been found to be effective in reducing erosion rates. However, their expensive production and synthesis processes present economic challenges and environmental concerns.

Arid climates, due to their specific ecological structure, are more sensitive and vulnerable to environmental changes compared to other climates. The overexploitation of salt brine and the drying up of the Khor and Biabanak Salt Lake will have negative ecological consequences for the surrounding areas and their residents. Changes in population distribution and forced migration could be one of the negative outcomes of the drying up of the Salt Lake playa. The continuous decline in the quality of water and soil resources suitable for agriculture will gradually reduce water and soil productivity, leading to the unsustainability of agricultural and livestock activities in the surrounding areas. Additionally, the wind blowing from the playa will cause the transfer of salt dust to cities and residential areas, increasing air pollution and resulting in respiratory and skin problems among residents. The drying of the Salt Lake playa will also have adverse effects on vegetation, directly impacting biodiversity. The reduction in the land's ability to support local plants and animals constitutes a form of environmental degradation (Kiani *et al*., 2024). Addressing this comprehensive challenge requires collaboration among different segments of society, governments, and researchers to provide effective solutions. While Khour and Biabanak playas are less affected by water shortage stress due to constant groundwater flow towards these palays, it is essential to maintain a balanced and stable withdrawal of brine to prevent subsequent problems.

One notable characteristic of the calcium and magnesium chloride solution is its high density, which, when mixed with sand particles, can increase their weight and minimize the impact of wind on particle dispersion. It is important to note that mulch sourced from natural materials tends to have fewer environmental consequences. For instance, the pebble mulch studied by Ahmadi and Ekhtesasi (1998) exhibits this quality.

The use of a combined calcium and magnesium chloride solution has a longer history outside of Iran. The acceptable durability of the combined calcium chloride and magnesium chloride solution used in this research confirms its significant longevity, which is consistent with the findings of Shan and Huck (1999). They investigated the use of chemical products for stabilizing mountain roads and concluded that chemicals are effective for road stabilization, with 64% of the classes related to chloride materials ($MgCl_2$, $CaCl_2$, ...), 8% to clays, 18% to bitumen coating, and 6% to adhesives. They also considered the longevity of chloride materials and coating bitumen to be greater than that of other chemical materials.

The combination of the solution with clay did not show significant differences compared to using the pure solution in terms of the studied parameters. However, Diouf *et al*. (1990) mentioned that adding clay to existing particles can positively contribute to stabilizing fine-grained sands. Their study indicated that the soil grains' resistance to crushing increases with higher clay content, but this effect is more pronounced when clay is used alone. The combined solution used in this research is effective in preserving particles without the need for additional materials. The use of chloride compounds enhances certain soil resistance characteristics. Abood *et al*. (2007) found that $CaCl_2$, $MgCl_2$, and NaCl salts increase soil density in the dry state and reduce plasticity, thereby decreasing compressive strength in silty clay soils. These factors collectively enhance shear resistance.

The specialized American site Desert Mountains (Desertrntricorp) states that Road Saver is a high-purity $MgCl_2$ material used for dust control and road protection. This material is moisture-absorbent and resistant to water evaporation. The recommended application rate for dust control is 0.3-0.5 gallons per yard. The amount of solution used in this research for controlling dune movement is equivalent to the quantity typically used for stabilizing dirt roads.

When using various types of mulches, it is important to consider their longevity and their ability to protect soil particles from wind erosion. Environmental factors highlighted by Refahi include adhesive properties, non-toxicity, absence of aromatic substances, permeability, temperature regulation, maintaining acidity within permissible limits, ability to blend with soil, and cost-effectiveness. Previous studies by Naseri *et al*. (2014) have demonstrated the stability and adhesive properties of this mulch solution. Analysis results indicate that the substance is non-toxic, sourced from desert waters, and free of aromatic compounds. The environmental impact of calcium chloride has also been noted to be minimal by Dris and Niskanen (1999).

To mitigate the negative impacts of oil mulches and reduce costs, it is recommended to use a combination of calcium and magnesium chloride solution. This solution is more cost-effective and has fewer adverse effects. The study conducted in this project suggests applying 2.5 liters per square meter of the stabilizing $CaCl_2$ and $MgCl_2$ solution on active sand fields to stabilize the sands. This method creates a protective layer of suitable thickness that can last for at least one year, protecting against erosion caused by particle impact.

Authors Contributions

All authors contributed equally to the conceptualization of the article and writing of the original and subsequent drafts.

Data Availability Statement

Data available on request from the authors.

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Ethical considerations

The author avoided data fabrication and falsification.

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Conflict of Interests

The author declares no conflict of interest.

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