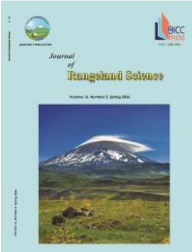

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Research Article

Innovative Windbreaks Using *Kochia Scoparia* L.: Transitioning From living to Non-Living Structures in Arid Regions of Iran

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Abstract

Wind erosion is a significant environmental challenge in arid and semi-arid regions, particularly where soil salinity and water scarcity limit the effectiveness of traditional control methods. Establishing living windbreaks for dust suppression is not cost-effective in these water-scarce and drought-prone areas due to their high irrigation requirements. This study introduces an innovative approach in which a plant species initially functions as a living windbreak. After reaching its maximum height, irrigation is halted, allowing the plants to transition into non-living windbreaks. *Kochia scoparia* L. Schrad was identified as a suitable species for windbreaks on highly saline land. In this research, seeds were sown in five rows using a strip planting method oriented against the prevailing wind direction, with 3 meters between rows and each strip extending 7 meters.Once the plants reached full growth, they were dried to serve as non-living windbreaks. Soil erosion and sedimentation rates were measured using sediment traps placed at the start of the rows and between rows; the collected data were analyzed. For greater accuracy, the same method was also conducted in a laboratory and within a wind tunnel. Wind speed at the windbreak location decreased from 17.8 m/s to 8.17 m/s, demonstrating the effectiveness of plant-based windbreaks in reducing wind speed. Wind erosion significantly decreased, with dust accumulation dropping from 1,464 g in the control to 808.2 g in the fifth row of windbreaks. These findings support using *Kochia scoparia* as an effective dual-purpose solution for sustainable wind erosion control in arid regions.

Keywords: Shelterbelt, Soil erosion control, Land degradation, Desert, Iran

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1. Introduction

Wind erosion poses a major threat to land productivity and environmental stability in arid and semi-arid regions, contributing significantly to land degradation, reduced agricultural production, and dust emissions (Zobeck & Van Pelt, 2016; Ravi et al., 2011). While living windbreaks have proven effective in reducing wind speed and controlling soil erosion, their application is often limited in water-scarce and saline regions due to high irrigation demands and maintenance costs (Funk & Reuter, 2021).

Soil erosion control has received more attention in recent years (Barrena-Gonzalez et al., 2020). Wind erosion is a key indicator of land degradation in arid and semiarid regions globally, which leads to dust storms as a direct consequence (Borrelli et al., 2016). The expansion of desert areas and the intensification of desertification, driven by climate change and human activities, present serious challenges globally, particularly in Iran. Wind erosion hotspots continuously threaten urban areas and agricultural productivity, causing substantial, economic, and security costs. Over the past 50 years, numerous efforts have been made to combat erosion and dust, many of which have yielded positive results. In recent decades, various mechanical and biological methods have been applied globally to mitigate wind erosion; however, many have encountered economic and operational challenges, especially in regions with poor soil conditions, limited water resources, and insufficient long-term support (Cornelis & Gabriels, 2005; Naghizadeh Asl et al., 2021). This highlights the need for cost-effective, low-maintenance, and ecologically adaptive alternatives. Long-term maintenance expenses in desertified areas, such as continued irrigation, annual replanting, periodic tray emptying, pruning, pest control, and weed management, increase the costs and reduce operational efficiency. The movement of sand dunes under erosive winds in active zones exacerbates the harmful effects of wind erosion on economic, social, and environmental sectors worldwide. Historically, this phenomenon has threatened and even buried entire settlements under sand drifts. In response, various methods, including the construction of windbreaks, have been developed to mitigate these risks (Borrelli et al., 2016; Kenney, 1987; Wu et al., 2013).

Windbreaks, regardless of their type, have proven effective in reducing wind speeds in erosive areas. The choice of windbreak type depends on factors such as project goals, available resources, materials, labor, and ecological conditions (Rosenberg, 1974). Vegetation plays a crucial role in mitigating wind erosion, with factors such as plant height, density, and species composition significantly influencing the movement of sand particles. Vegetation shields bare soil from direct wind exposure, improves soil structure, enhances organic matter content, and promotes soil particle cohesion. Windbreaks—whether natural, such as trees, or artificial barriers—are widely used in agriculture and mining to control airborne particles by reducing wind velocity. Wilson (1985) conducted a study using 2.2 m height choppers with adjustable densities to examine the impact of windbreak permeability on wind speed reduction. The researcher classified windbreaks with 15-20% permeability as dense, those with over 45% as non-dense, and those in between as semi-dense. The findings revealed that dense and semi-dense windbreaks begin to affect wind speed at a distance of 8 times the windbreak's height in front and 30 times the height behind (Kenney, 1987; Tamang et al., 2009; Lampartová et al., 2015). Dense windbreaks had a greater effect on wind speed reduction in front and up to 4 times the height behind, compared to non-dense ones. However, beyond 4 times the height, non-dense windbreaks became more effective. Hagen (1996) investigated windbreaks with porosities of 20% and 40% to assess their impact on wind reduction and erosion control. Cook & Goyens (2008) suggested that in a system of dense windbreak rows, wind speed decreases after encountering the first row, with a greater reduction by the second row. Wang et al. (2010) initiated the "Three Norths Forest Shelterbelt" project in China to combat desertification and mitigate dust storms, although concrete evidence supporting its success remains limited. Kohli et al. (1990) examined Eucalyptus windbreaks in Indian winter agricultural systems and noted that the distance from the windbreak significantly impacted crop parameters. Vacek et al. (2018) evaluated the impact of three types of windbreaks on controlling wind erosion in the Czech Republic. The results indicated that diverse windbreak structures could effectively reduce wind speed and play a significant role in soil conservation.

Windbreaks are narrow strips of trees, shrubs, and/or grasses planted for the protection of farms, buildings, canals, and other areas from the wind and blowing sandstorms (Udhaya Nandhini & Sakthinathan, 2017). Studies and experiments have shown that one or two rows of tall and thick grass plants with 9m intervals can reduce wind speed and wind erosion up to 90% (Brandle et al., 2004a; Hagen, 2001). The windbreaks guide the blowing wind upwards, which, after a certain distance - depending on the height of the windbreak–will return to surface level (Arazi et al., 2011). So far, several studies have been conducted on the reduction of wind erosion due to the creation of windbreaks. These include the studies by Mohammad et al., (1996) in Sudan, Foereid et al., (2002) in Denmark, and Cornelis & Gabriels (2005) in Belgium. Various windbreak systems have been installed globally to control wind erosion (Brandle et al., 2004b). Living windbreaks, often composed of perennial species, are durable and stable. However, that study presents an innovative model that utilizes an annual species with rapid growth, making it suitable for areas with limited water and saline soil conditions. *Kochia scoparia* plays a significant role in controlling wind erosion due to its ability to create dense vegetation cover, stabilize soil with its strong root system, and reduce wind speed near the ground. It helps retain soil moisture by limiting evaporation and protects soil organic carbon by minimizing erosion. This plant is also highly adaptable to arid and saline conditions, making it effective in erosion-prone areas. However, its use must be carefully managed as it can become invasive and compete with native species in certain ecosystems (Sabaghnia et al., 2015; Iverson et al., 1982)

Kochia scoparia L. (Schrad.) is an annual herbaceous dicotyledon from the Chenopodiaceae family, well adapted to arid regions due to its extensive root system, which can reach depths of up to five meters and spread laterally up to seven meters. It thrives in highly saline soils, often being the only plant in such areas, and is a key species in arid environments. This plant serves as an effective windbreak option for saline lands (Sabaghnia et al., 2015; Iverson et al., 1982).

As a salt-tolerant halophyte, *Kochia* is among the preferred species for saline irrigation, offering valuable fodder. It has favorable characteristics such as height, a high leaf-to-stem ratio, and significant fodder yield. However, intense intraspecific competition can reduce the plant's height by half, to about 50 cm. In competitive conditions, *Kochia* grows upright to 200-250 cm, while in non-competitive settings, it adopts a bush-like form, typically reaching 90-120 cm in height due to efficient water absorption via its deep roots (Salehi, 2015).

Advantages of the *Kochia* plant can be summarized as Iverson et al. (1982):

1) C4 Metabolism: *Kochia* is a plant with a C4 metabolism, which makes it highly dependent on light and less tolerant of low-light conditions.

2) High Salinity Tolerance: The plant tolerates high salinity levels, even exceeding 30 dS/m, which makes it suitable for growth in saline environments.

3) Forage Production: Due to its high tolerance to salinity and rapid growth, *Kochia* has the potential to partially meet the forage needs of small livestock, especially in saline regions where forage is scarce.

4) Seed Production for Oil Extraction: *Kochia* seeds contain 10–11% oil, making them a viable option for edible oil production, and

5) Windbreak in Arid and Rangeland Areas: With its rapid growth and woody nature at the end of its growth cycle, *Kochia* can effectively be used as a windbreak in desert and rangeland areas.

In some regions, biological desertification control is not feasible due to limitations in soil quality, water resources, and other factors. In such cases, non-biological methods—such as mulches, earth covers, and windbreaks—are recommended. This study addresses this research gap by introducing *Kochia scoparia*, a fast-growing, salt-tolerant annual plant, as a dual-purpose windbreak. Initially, it functions as a living barrier; after irrigation ceases, it continues to reduce wind speed as a dry, structural windbreak. The effectiveness of this approach is evaluated through both field trials and controlled wind tunnel experiments. However, these methods also have limitations, including high costs and uncertainty about their long-term effectiveness. This research evaluates the effectiveness of the proposed approach through both field trials and controlled wind tunnel experiments. Previous conventional methods for wind erosion control have shown limitations, including high costs and uncertainty about their long-term effectiveness, which this study aims to address.This innovative method, using *Kochia scoparia* with a high growth rate, minimal water consumption, and deep roots tolerant to salinity, may help address these challenges. This research was carried out in both field and laboratory to evaluate wind erosion control using *Kochia Scoparia* windbreaks under natural conditions and controlled laboratory environments.

2. Materials and methods

2.1. Study area

Iran is geographically located in the southern half of the temperate belt in the northern hemisphere, within the world's arid and desert belt. Much of this area overlaps with the air subsidence zones in the general circulation model of the atmosphere. The deserts of Iran are classified as some of the driest regions in the world. Isfahan province, situated in one of Iran's arid and semi-arid regions, spans a total area of 1,952 km2, of which approximately 1,863 km2 are plains, with the remainder being highlands (Figure 1).

The study area in Borkhwar region (Isfahan Province, Iran) lies between 1,590 and 1,600 m a.s.l. and experiences low annual precipitation (50–200 mm) with high annual evaporation (~2,000 mm) and frequent strong north–south dry winds that contribute to dust generation and land degradation (SWRI, 2019). The soils are predominantly azonal and zonal, highly saline, with poor infiltration and prismatic or cubic structure enriched with gypsum and lime, leading to low-quality land prone to erosion (Shirazi & Jafari, 2010).

2.2. Field experiments

In this study, we employed both field experiments and controlled wind tunnel tests to evaluate the performance of *Kochia scoparia* windbreaks. The field study involved identifying the erosion-prone zones based on field visits, satellite imagery analysis, and wind pattern data (wind roses). Using GIS tools, susceptible areas were mapped. Wind data, including direction and speed, were obtained from the closest meteorological stations. According to these statistics, the prevailing wind in the area blows from the northwest; therefore, the rows of windbreaks were oriented perpendicular to this wind direction to maximize their effectiveness.The annual average speed of prevailing winds in study is approximately 2.5 meters per second (m/s). This value represents the average wind speed throughout the year for winds that occur most frequently. The wind erosion threshold in the study area was measured using a portable wind tunnel. he wind erosion threshold in the field was 4.63 m/s, and natural wind events in the area frequently exceed this value, resulting in significant soil loss.Soil from different depths was analyzed for pH, EC, N, P, K, organic content, gypsum, lime, texture, and bulk density (Table 1). The soil in this region has a neutral to slightly alkaline pH (7.8–7.9) and contains sufficient potassium and phosphorus in the surface layers. However, it faces significant challenges such as high salinity (up to 71.1 dS/m in the surface layer), low nitrogen content (0.02–0.03%), and a sandy texture, which reduces water retention. These factors limit the growth of most plants, making them suitable primarily for salt-tolerant species like halophytes.

The size, dimensions, and number of windbreak rows were determined based on the erosion threshold speed and soil test results for proper implementation. Research on the length, width, and number of windbreaks indicated that the length of the windbreak depends on the area to be protected and should typically exceed the width of the protected area. This is because at both ends of the windbreak, wind speeds tend to increase, often reaching 120% of the wind speed in unprotected areas (Cornelis et al., 2000). According to widely accepted windbreak design guidelines, such as those used in the United States and Australia, the effective length of a windbreak is recommended to be at least 12 to 20 times the height of the vegetation (Wang et al., 2010; Brandle et al., 2004a).

In the present study, the windbreak length was set at 7 m, equivalent to approximately 10 times the average height of *Kochia scoparia* (70 cm). This decision was made not only due to spatial limitations in the wind tunnel experiment but also to reflect practical field conditions where constraints such as land availability, implementation costs, and real-world land use patterns make it challenging to establish longer windbreak structures. The width of the windbreak refers to the number of rows of plants and shrubs used. The ideal thickness for a windbreak is 4 to 10 rows of plants.

In this plan, five rows of windbreaks were used, with a distance of 3 m between rows, based on the wind erosion threshold. The project was implemented using the *Kochia scoparia*, planted from seed in both spring and fall. Figure 2 provides a concise visual summary of the sequential steps undertaken in both the field and laboratory phases of the study. It serves as a schematic overview to assist readers in understanding the workflow, particularly the transition from living to non-living windbreak implementation.

Experiments were performed using 5 treatments (rows) and a control (without a windbreak) in three repetitions. The seeds were sown in rows along furrows (Figure 3). In the spring cultivation, the maintenance period was 4 months. Irrigation was done weekly in the first month, then every 10 days in the second month, and every 15 days in the third and fourth months. At the end of the fourth month, when the plants had gone to maturity and had achieved their maximum growth, irrigation was stopped.

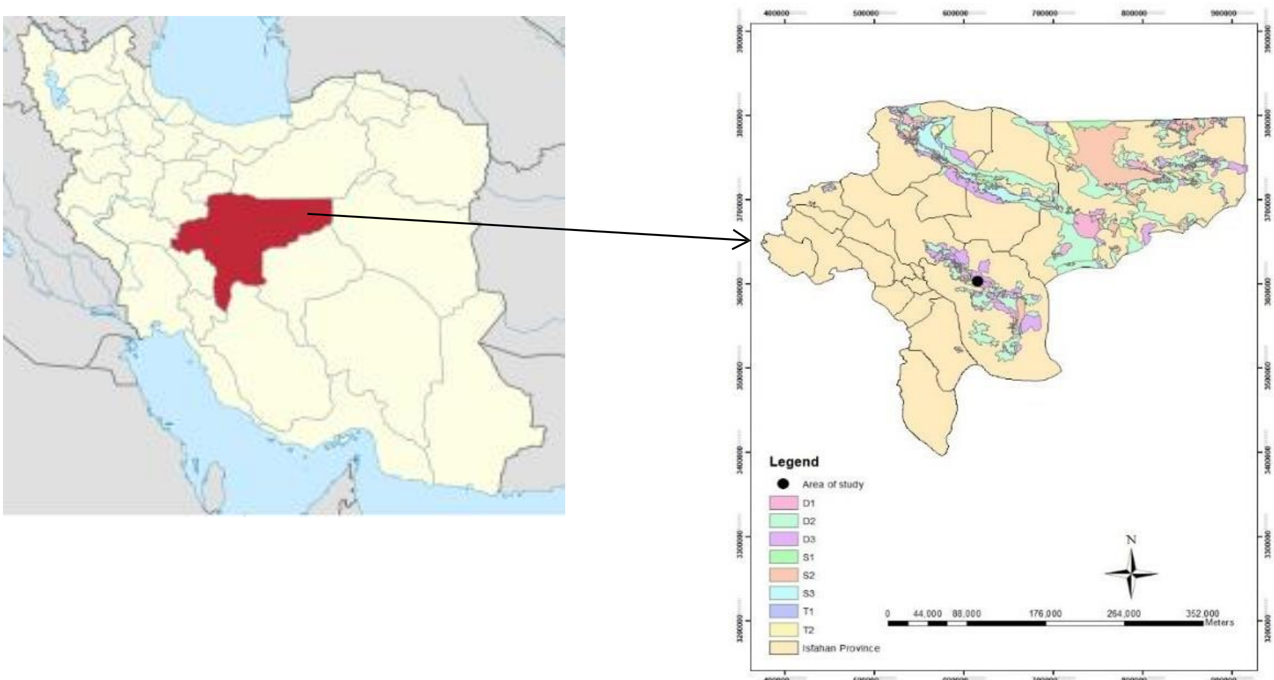

Figure 1. The map on the left shows the country of Iran, and the right shows the Isfahan province and the bold circle is the location of the study area and wind erosion crisis center

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Table 1. Soil test results of the study area

Parameter	Wind deposits on the soil surface	0-15 cm Soil layer	15-25 cm Soil layer	25 cm< Soil layer
pH	7.8	7.8	7.8	7.9
EC (dS/m)	32.7	71.1	45.1	15.9
N%	0.03	0.03	0.02	0.03
K (mg/kg)	337.2	831.5	820.4	787.1
P (mg/kg)	28	30	26	24
$CaCO_3$ %	26.4	28.1	28.9	29
Ca (meq/100)	80	44	40	-
Mg (meq/100)	100	68	60	-
OC%	0.35	0.33	0.27	0.39
$CaSO_4$%	1.1	3.2	3.2	2.4
Bulk density (g/cm^3)	-	1.2	-	1.6
Clay %	9	25	29	31
Silt %	26	50	48	48
Sand %	65	25	23	21

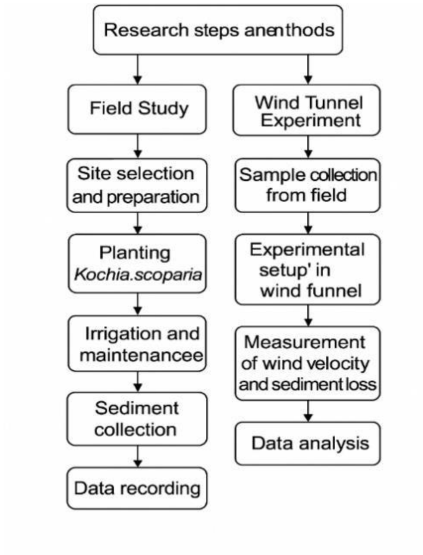

Figure 2. Flowchart of research steps and methods

Figure 3. The form of implementation in the study area

In the fall cultivation, irrigation was applied weekly for the first two weeks, once every 10 days during the second month, and once every 15 days in the third month, after which irrigation was stopped. In both the spring and fall sowing dates, before stopping irrigation, plant measurements were taken, including survival percentage and plant dimensions (length and width).

Erosion and sedimentation in the treatments were measured by installing trays (sediment traps) at the beginning of the rows and between the rows. One of the most common tools for measuring creep materials is horizontal sediment traps, which are made from a metal box with dimensions of 300 × 100 × 200 mm and placed between the planted rows. Studies have shown that 80 to

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90% of sand transport capacity by wind occurs at a height of 20 to 30 cm above the ground. Within this range, most sand is transported at a height of 10 cm above the ground. Therefore, if soil or vegetation barriers are established at heights between 30 to 50 cm and up to a maximum of 100 cm, most of the sand carried by the wind can be controlled (Xie et al., 2019). Therefore, with these sediment traps, the suspended movement of sand, in addition to creeping and saltating particles, can also be studied. The weight of sediments from the sediment traps was measured and recorded after four dust events. This occurrence was documented separately for plantings in the spring and fall seasons.

2.3. Laboratory wind tunnel experiment

To measure the wind erosion threshold in a laboratory, a wind tunnel set up by the Research Institute of Forests and Rangelands in Tehran was used. The wind tunnel tray dimensions were 8×30×50 cm (with tray area equal to 1500 cm²). It was filled with soil from the same location where the *Kochia* plant (windbreaker) was planted. The device was calibrated following the method of Irwin (1981), using roughness elements and pyramidal structures, with hot-wire and temperature sensors adjusted against standard profiles to ensure accurate wind flow simulation. This method is specifically designed for regulating and analyzing wind flows in tunnels, with results confirming the accuracy of the experiments.

To better replicate natural conditions and account for the soil surface roughness of the region, the soil was used in its unsieved, dry state with surface clods. In each stage, the tray was filled with soil, weighed, and placed in the wind tunnel. After activating the device, the tray was exposed to wind for 2 minutes and then reweighed. Soil moisture content was measured as 14% by volume using a portable TDR device.

The recorded wind speeds were 8.17, 15.80, and 24.60 m/s. By solving the regression equation for zero g of wind sediment (Y = 0), the wind erosion threshold speed (X) was calculated in the wind tunnel. Therefore, the wind erosion threshold speed was calculated as 4.29 m/s.

Figure 4 illustrates a simplified layout in which the plants are shown schematically. However, in the actual wind tunnel experiment, the windbreaks were implemented as continuous belt plantings. Wind speed was measured at ground level before the first row, between the rows, and after the last row to evaluate the effectiveness of the windbreak system.

In the wind tunnel experiments, dried *Kochia* plants—representing the non-living phase after irrigation is stopped—were used to simulate their function as physical windbreaks under field conditions. Typically ranging in height from 75 to 103 cm, the windbreaker's height was adjusted to fit within the wind tunnel constraints, averaging around 40 to 45 cm. The plant's structure, characterized by gaps between its small and large branches, allows for fluid (wind) permeability. Using AutoCAD software, the windbreaker's permeability was assessed through image scanning. with a density of 59% (41% space), this windbreaker falls into the category of semi-dense windbreakers. Windbreakers with 20-45% space are similarly classified as semi-dense (Wang et al., 2010; Wu et al., 2013).

It is important to note that these calculations were conducted solely for wind tunnel simulations. In natural settings, densely packed rows of windbreakers are expected to yield more favorable outcomes. The total area of the rectangular image was computed as 171.8 cm2, with the windbreakers occupying 101.4 cm2, representing 59% of the total area.

To measure wind erosion, sediment traps were placed between the rows of *Kochia* plants, and comparison tools were set up in a control area. The trays were weighed after each event to record the amount of dust collected. Data from the fall and spring seasons were analyzed separately using Minitab 16 software. ANOVA was performed to assess the treatment effects, with Tukey's test used to compare means at a 5% error level. Six treatments (first to fifth rows and control) were applied in two seasons with three repetitions each.

3. Result

3.1. Field experiment under natural conditions

The *Kochia* species was cultivated in the Barkhor, Isfahan province, in two seasons, spring (April 2021) and fall (December 2020). Initially, they served as living windbreaks and later as non-living windbreaks. In April 2021, seeds of *Kochia* were sown in five rows with a 3-m spacing between rows and a row length of 7 m. allowing the plants to reach a maximum height of approximately 60 cm. Irrigation was then stopped, and the dried plants were used as non-living windbreaks to reduce wind speed and mitigate wind erosion. The same conditions were replicated in December, where the plant height reached about 100 cm. After reaching maximum height, Irrigation was stopped, leaving the dried plants with strong roots in the soil. These plant typically persists for several years in the environment and, due to their rapid growth, are highly suitable for controlling soil erosion through reducing wind speed. The *Kochia* seed germinates well when the air temperature reaches 20 to 25°C during the day. The highest germination rate is observed in non-saline environments, while an increase in water salinity delays sprouting and initial seedling growth. However, planting *Kochia* can still succeed in highly saline soils due to its rapid germination. Studies conducted in various counties of Iran showed that after the sprouting stage, an increase in water salinity to 28 dS/m in Birjand, Iran, led to a 36% reduction in yield. In contrast, in Golestan Province, no significant decrease in biomass production was observed at a salinity up to 21 dS/m. Similarly, in Razavi Khorasan Province, an increase in water salinity up to 23 dS/m had no impact on biomass production.

Studies also showed that increasing the irrigation interval from 7 to 14 days resulted in a 25% reduction in dry matter production in Birjand. In contrast, in Golestan Province, even providing 50% of the water requirement was sufficient for this plant. Implementing deficit irrigation methods was more favorable in non-saline treatments up to a salinity level of 21 dS/m, but for higher salinity levels, 100% of the plant's water requirement must be met (Salehi, 2015).

Results of (ANOVA) showed significabt differences betweeb treatments ($p<0.05$). In this experiment, six treatments (first row, second row, third row, fourth row, fifth row, and control) were considered across two seasons, with three repetitions per season (Table 2).

The result showed a significant impact of windbreak row treatments on reducing soil erosion in spring (Table 2). *Kochia* windbreaks significantly reduced wind speed and sediment deposition compared to control plots. Result revealed the highest dust accumulation (1397 g) was obtaned in control, while row 5 recorded the lowest at 808.2 g (Table 2).

In fall season, results showed a significant impact of windbreak row treatments on erosion control ($P<0.01$). These findings suggest that planting *Kochia* species in multiple rows had a positive effect on wind speed reduction. The mean comparison indicates that the greatest dust accumulation (1532 g) was recorded in the control treatment, while the lowest value of (1036 g) was observed in row 5. Result revealed that the greatest deposition occurred in the control treatment (1464 g), while the least deposition was observed in row 5 (922 g); this value was not significantly different from that of row 4 (Table 2).

In spring, sediment weight was significantly lower than in fall, with the fifth row collecting the sediments being 808.2 g and 1,036 g in spring and fall, respectively (Table 2).

The results of two-season cultivation showed a significant reduction in wind erosion across planting rows ($P<0.01$), with the highest sediment in the control and the lowest in row 5. While no interaction between seasons was found, erosion consistently decreased in both, with lower rates in spring due to taller, denser *Kochia* growth (Figure 5).

In spring, the average plant height reached 60 cm, while in fall, this height increased to 100 cm due to better water availability. These differences affected sediment levels, with a 25% reduction observed in spring. Spring cultivation showed better performance in wind erosion control, likely due to higher plant density and more favorable environmental conditions.

3.2. Laboratory wind tunnel experiment

For a more accurate evaluation, the method was also tested in a controlled laboratory environment using the wind tunnel. 60 kg of soil from the study area was sent to the Research Institute of Forest and Rangelands, Tehran, Iran, along with an appropriate number of *kochia* plants to create different rows in the wind tunnel.

Before and following the installation of the windbreaker within the wind tunnel chamber, wind speed was measured using a digital anemometer.

In the first treatment, where a single row of semi-dense dried *Kochia* windbreak was placed in the wind tunnel, measurements showed that the wind speed decreased to 5.3 m/s after the windbreak was installed.

The statistical comparison of wind speeds among the treatments and the control sample was performed at three fan settings in the wind tunnel corresponding to nominal free-stream wind speeds of 17.8, 15.8, and 24.6 m s^{-1}. These values are now indicated in table 3. One-way ANOVA showed that, based on F-values, there was a notable difference between the control and windbreak treatments. Installing a single row of windbreaks at these speeds reduced the measured wind speed at the test location.

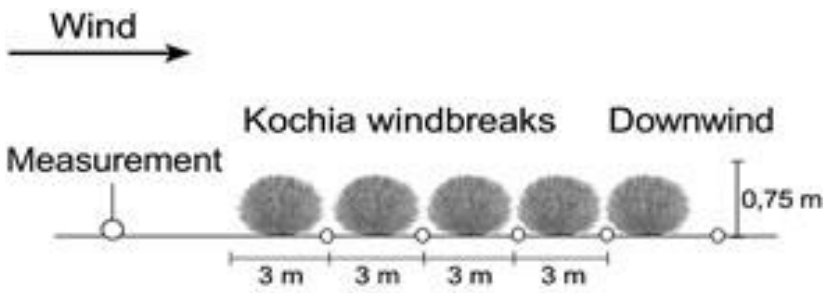

Figure 4. Schematic of wind tunnel setup with five *Kochia scoparia* windbreak rows

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Table 2. Mean comparison of average sediment across rows in the spring season

Treatment	Sediment in Spring (g)	Sediment in Fall (g)
Control	1397.3a	1532a
Row1	1034.6b	1341ab
Row2	1014.3b	1314b
Row3	975.4bc	1240c
Row4	853.4cd	1103cd
Row5	808.2d	1036d

Different letters (a, b, c) within columns indicate significant differences between treatments

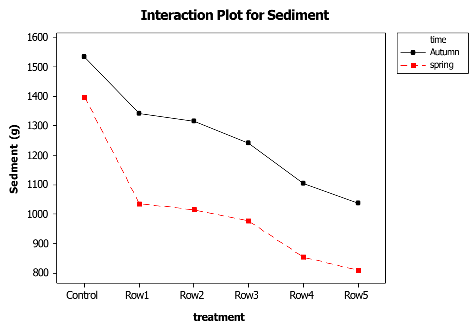

Figure 5. Comparison chart of sediment changes collected in the sediment trap in different rows and

Table 3. Wind speed before and after installing a single row of semi-dense Kochia windbreak in the wind tunnel at three fan settings (nominal free-stream speeds: 17.8, 15.8, and 24.6 m s⁻¹)

Fan setting (m s^{-1})	Wind speed before installation wind breaker (m/s)	Wind speed after installation wind breaker (m/s)
17.8	9.8	5.3
15.8	21.1	18.1
24.6	28.2	26.80

Note: Fan speeds (17.8, 15.8, and 24.6 m s^{-1}) are nominal free-stream settings. The reported values are local wind speeds measured at specific points in the tunnel, which may exceed the nominal setting due to flow acceleration through the semi-dense windbreak

4. Discussion

This study demonstrated a significant reduction in wind speed and sediment deposition using *Kochia scoparia* windbreaks under both field and wind tunnel conditions. The data showed that the vegetation effectively decreased surface wind velocity and enhanced soil stability. These findings confirm the critical role of plant-based barriers in mitigating wind erosion.Previous research has also emphasized the role of vegetation-with variations in height, density, and porosity, in disrupting sand particle movement, enhancing soil structure, and limiting wind–soil interaction (Mirhasania et al., 2019). In light of current challenges such as dust storms, sand movement in erosion-prone lands, and resource scarcity in arid zones, the use of fast-growing, salinity-tolerant species like *Kochia* becomes increasingly relevant.

The findings of this study demonstrated that *Kochia scoparia* could effectively function both as a living and a non-living windbreak under arid conditions. Experimental results confirmed its adaptability to saline and water-scarce soils, as well as its capacity to significantly reduce wind speed and sediment transport, making it a cost-effective alternative to conventional erosion control methods. These findings emphasize the practical implications of integrating fast-growing, salt-tolerant species in desertification control strategies, particularly in water-scarce regions. This study aimed to introduce a rapidly growing, one-year plant that requires minimal irrigation and is salt-tolerant in desert areas. Field studies conducted in the region utilized the indigenous *kochia* plant, which thrives under such conditions. Initially planted as a living windbreak, irrigation was ceased once the plants reached a certain height, allowing the dried plants to serve as passive wind barriers to diminish wind velocity. Numerous research efforts have focused on mitigating wind erosion by erecting barriers to impede wind flow. Woodruff & Siddoway (1965) demonstrated that the presence of plant residues decreases wind speed. Similarly, Fryrear (1985) suggested that covering 30% of the soil surface with plant remnants could reduce soil loss by 80%.

By considering the prevailing wind direction and calculating the wind erosion threshold speed in the region, the *kochia* plant was strategically planted in five rows, with a 3 m gap between each row and a length of 7 m for each row, during both spring and fall, with three repetitions. Studies indicated that multi-row windbreaks are notably more effective than single-row ones (Wu et al., 2013; Chang et al., 2019; Li et al., 2023). The efficacy of windbreaks depends on various structural attributes, including windbreak height, porosity, density, width, the number of rows, spacing between bushes in each row, and wind speed (Brandle et al., 2004b; Foereid et al., 2002; Woodruff & Siddoway.,1965). In this study, the *kochia* plant was sown in both spring and fall under identical conditions, reaching a maximum height of 60 cm in fall and over 100 cm in spring. *Kochia* is a halophyte plant capable of tolerating high levels of soil and water salinity, up to 30 dS/m. These findings align with previous research, which also demonstrated that multi-row windbreaks composed of salt-tolerant species can significantly reduce wind erosion in arid landscapes(Wu et al., 2013; Chang et al., 2019). However, unlike those studies that used perennial species with high maintenance needs, the present study highlights the potential of a fast-growing annual species that functions in both living and non-living phases. At higher salinity levels, such as 28 dS/m, its yield can decrease by 36%, but at lower salinity levels, its biomass production is no affected. Under competitive conditions, *Kochia* can grow to a height of 200–250 cm, while in non-competitive environments, it typically reaches 90–120 cm. *Kochia* is versatile in its applications, initially serving as a living windbreak and later transitioning into a non-living windbreak. Its biomass is also suitable for animal feed, and its seeds contain 10–11% edible oil. Experiments showed that *Kochia* effectively reduces wind speed from 17.8 m/s to 8.17 m/s and significantly decreases soil erosion in both spring and fall, with higher erosion observed in fall. Specifically, sediment accumulation decreased by 42% in spring and 32% in fall when comparing the fifth row treatment to the control. These reductions highlight the plant's effectiveness in mitigating wind erosion under both seasonal conditions

Based on general design standards for windbreak construction, non-living windbreaks are typically recommended to have heights between 50 and 150 cm, excluding the foundation (Hong et al., 2019; Kučera et al., 2020; Li et al., 2023).

The windbreak, with a porosity of 40%, falls into the category of non-dense windbreaks. Once the *kochia* plant has been irrigated four times and has reached its peak height, irrigation ceases, and it functions as a non-living windbreak. A wind deposit measurement tool (tray) was positioned between the windbreak rows, and soil moisture levels were determined at the start and end of the study. This research indicated that wind erosion is directly proportional to the third power of wind speed. A slight decrease in wind speed results in a significant reduction in erosion. The presence of a vegetation canopy plays a vital role in wind erosion, influencing deposition potential. When the vegetation canopy exceeds a specific threshold, it reduces the adverse impacts of other factors such as soil texture, wind speed, and land surface flatness. Furthermore, in addition to lowering wind speed, the canopy retains moisture, enhances particle adhesion, and promotes continuity, thereby limiting particle movement and reducing wind erosion on the land surface) Kučera et al., 2020; Torshizi et al.,2020).

In general, it can be stated that this windbreak initially functions as a living windbreak, providing benefits such as carbon absorption, oxygen production, and support for biodiversity. After drying, its structure serves as a physical barrier to reduce wind speed. Also, a living windbreak requires water and regular maintenance during its active period, whereas a dry windbreak involves significant costs for installation and establishment. Studies conducted by Baghestani Meybodi & Zare kia in 2020 demonstrated that planting (Haloxylon species) as a windbreak incurs significant costs related to planting, maintenance, and irrigation. Additionally, studies by Ladenburger et al. (2006) demonstrated that the Tamarix shrub, when used as a living windbreak, consumes a significant amount of water, leading to an increase in the depth of the groundwater Table and ultimately causing desiccation in the habitat.

5. Conclusion

Overall, the findings of this research highlight the crucial role of windbreaks in reducing wind speed and mitigating wind erosion. Multi-row windbreaks can be effectively employed to control wind speed and erosion in areas severely affected by wind erosion and dust storms. These windbreaks demonstrate high effectiveness across a range of wind speeds and storm intensities. Notably, sediment levels measured in traps during the spring planting were lower compared to those observed in the fall planting. For example, the control treatment accumulated 1,464 g in spring and 1,532 g in fall. The fifth row had the lowest sediment deposition, with 808.2 g in spring and 1,036 g in fall. The presence of *Kochia* windbreaks significantly reduced wind speed at the windbreak location from 17.8 m/s to 8.17 m/s. Therefore, It was recommended to utilize multi-row windbreaks, especially in regions experiencing severe wind erosion and dust storms.

This study demonstrates that by planting the seeds of the kochia plant, an annual species with low irrigation requirements and high salinity tolerance, effective desertification operations can be conducted. Additionally, kochia can be established as a windbreak in front of agricultural fields.

Authors Contribution

Abbas Ghorbani conducted the experiment and written the first draft. Mojtaba Jafarzadeh Kenarsari supervised the project and analyzed the obtained date. Amin Farnia and Shahram Nakhjavan edited and reviewed the draft.

Conflict of interests

Authors declared no conflict of interest.

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Data availability statement

The data presented in this study are available on request from the corresponding author due to (specify the reason for the restriction).

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