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Evaluation the efficiency of different mulches to combat wind erosion of sandy soil running title: Efficiency of different mulches to control wind erosion

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ABSTRACT

This study was conducted to determine the most suitable mulch regard to environmental adaptation. It was carried out as a completely randomized design with treatments including cement mulch (50 g cement +100 g sand +1000 ml H_2O), two rates of polymer (5 and 10 g polyvinyl acetate + 1000 ml H_2O), two rates clay mulches (100 and 200 g zeolite + 1000 ml H_2O, 100 and 200 g bentonite + 1000 ml H_2O), and control (1000ml H_2O). After applying the treatments, trays containing moving sands together with different mulches air dried and the rate of soil erosion was measured during 20, 40 and 60 minutes by wind tunnel at a speed of 85 km h^{-1}. In addition, the penetration resistance, the abrasion resistance, crust thickness, and the impact strength were measured. Data were analyzed using SPSS software. The results of this study showed that the applied treatments increased the penetration resistance, crust thickness, impact strength, and abrasion resistance and reduced the wind erosion; so that 10g of polymer mulch and 200 g bentonite have the highest resistance against wind erosion and are recommended as suitable treatments for stabilization the moving sands in arid lands such as studied area.

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1. Introduction

The arid and semi-arid regions of the world are located at latitudes of 20 to 45 degrees in northern and southern hemisphere. Iran is also located in this region, known as worldwide erosion belt, and more than 64 percent of its area is consisted of arid and dry areas with no vegetation. These areas are sensitive to wind erosion, and dust storms. Almost 13 million hectares of sand dunes are located in residential regions, villages, margins of cities and agricultural lands, which more than 5 million hectares of them are active and semi-active sand dunes (Ekhtesasi et al., 2006), so their stabilization is necessary. Wind erosion is a function of two factors including wind speed and soil erodibility. On the other hand, the existence of dry soil and continuing repetitive winds are necessary for occurrence the wind erosion (Naghizade asl, 2017).

Wind erosion is one of the most important destructive agents in the soil. Reducing the wind speed or increasing surface roughness can be used as strategies to increase soil resistance against winds and combat the wind erosion. One of the fast and temporary solution for wind erosion and dust storm is the use of mulches on the soil surface. Obviously the soil surface is eroded by the shear tension of the wind unless it is protected by a suitable protective factor (Cornelis et al., 2004; Vidal et al., 2005). Over the past half century, various materials have been used to find suitable stabilizers for controlling wind erosion (Hagen, 2010), which includes using of plants (Fryear and Skidmore, 1985), oil mulch (Gholami Tabasi, 2015), gravel mills (Li, 2003; Li et al., 2001), mineral mulch (Duiker et al., 2001; Edwardsson, 2010), clay mulch (Charman and Murphy, 2000); sarbare mulch (Rodriguez et al. 1994); Polymer mulch (Samaei et al., 2006), Polyvinyl acetate

(Movahedan et al., 2011), polyacrylamide (Genis et al., 2013; He et al., 2008), soil stabilization resin (Jafari, 2014), micro silica-lime-clay (Naghizade Asl et al., 2017). Mineral mulch is widely used in Canada and the United States for dust control (Goodrich et al., 2009; Edwardsson, 2010). Mattar and Ameen (2015) used sodium silicate solution as a byproduct of glass and ceramic industry for stabilizing and improving the mechanical properties of sand dunes. They concluded that the application of sodium silicate solution to sand dunes increased drifting sands resistance against wind erosion and the best results occurred with the application of sodium silicate solution by 5% of dry weight of sand samples. Oil mulch has been used more than other mulches in Iran. However, regard to the environmental and economic disadvantages of them, the tendency to use natural and non-oil mulches with the least negative effect and highest stabilization is increasing now days (Naghizade Asl et al., 2017). Application the natural cheap and accessible materials as mulches has been attracted more attention. These materials including clay, Lime, gypsum with cementitious properties are very important in arid and semiarid area. Gypsum as a soil amendment containing calcium, is very important for improvement the soil physical properties (Emami and Astaraei, 2012). Clay mulches are resistant against wind flow, cheap, and environmental friendly. Production the cheap, environmental friendly and resistant mulch against the wind forces is essential in area that exposed the wind erosion in short term periods. The accessibility of bentonite and zeolite is convenient in Iran and they don’t damage the environment. Therefore, this study performed to investigate the effect of clay mulches (bentonite and zeolite) on wind erosion, and to compare their effectiveness with resin and cement mulches on reducing the wind erosion using a wind tunnel.

2. Material and Methods

Soil samples were taken from 0-30 depths of desert region with 60º 15′61″ E latitude and 36º 36 40″ N longitude. The study area is a critical areas of wind erosion which is located in Samad Abad village with an area of 59686 hectares at 32 km southwestern of Sarakhs town in Khorasan razavi province (Iran). The samples were air-dried and passed through 2 mm sieve to analyze physical and chemical properties of them.

2.1. Experimental treatments

This research was performed as a completely randomized design. To study the effect of different mulches on wind erosion, treatments included clay mulches i.e. bentonite at two rates (100 and 200 g + 1000 ml water; B1 and B2), and zeolite at two rates (100 and 200 g + 1000 ml water, Z1 and Z2), polymer mulch at two rates (5 and 10 g Polyvinyl acetate + 1000 ml water; R1 and R2), cement (50 g cement + 100 g sand + 1000 ml water) and control (1000 ml water) in three replications. Soil was homogenously filled into metal trays (43 cm in length, 25 cm in width and 2 cm in height), and their surface completely leveled. Then, 4 mentioned types of mulches i.e. polyvinyl acetate, zeolite, bentonite, and cement together with water were prepared by addition the water to a volume of one liter. The mixture was stirred for 5 minutes to obtain homogenous mulch, after then the prepared mulches were sprayed on soil surfaces of the trays. The treated trays were located in outdoors to achieve air dry condition for 10 days. The control treatment was simultaneously prepared.

2.2. Measurement penetration resistance, abrasive resistance, impact resistance, and surface crust thickness

Hand cone penetrometer was used to measure the penetration resistance of samples (Faramehr et al., 2014). The penetration resistance (kg cm^{-2}) was measured at 10 points of each sample. Also, the abrasion resistance was measured by sand paper, and its scoring was given according to Table 1 (Diouf et al., 1990). Typically, a special rod is used to determine the strength of brittle shells or hard layers on the soil surface. The number of impact and the penetration depth of the rods can be used to estimate the impact strength of the soil (Chepil, 1975). Scoring and classification the impact resistance was done based on Table 2 (Diouf et al., 1990). The thickness of the crust formed by mulching was measured at 10 points and the average of this points was used for data analysis.

Table 1. Scoring the abrasion resistance of treatments

class	How to rate the abrasion resistance
1	The surface crust is broken and the sand particles are separated if more than 30 times the abrasive sandpaper moved on crust layer.
0.75	The surface crust is broken and the sand particles are separated if 15-30 times the abrasive sandpaper moved on crust layer.
0.5	The surface crust is broken and the sand particles are separated if 5-15 times the abrasive sandpaper moved on crust layer.
0.25	The surface crust is broken and the sand particles are separated if 2-5 times the abrasive sandpaper moved on crust layer.
0	The surface crust is broken and the sand particles are separated if 1-2 times the abrasive sandpaper moved on crust layer.

Table 2. Scoring the impact resistance of treatments.

class	How to rate the impact resistance
1	Don't break the surface crust by releasing the rod.
0.75	The surface crust is broken and the rod drops to 1 cm depth into soil, when the rod is released.
0.5	The surface crust is broken and the rod drops to 1-2 cm depth into soil, when the rod is released.
0.25	The surface crust is broken and the rod drops to 2-4 cm depth into soil, when the rod is released.
0	The surface crust is broken and the rod drops to more than 4 cm into soil, when the rod is released.

2.3. Measurement the wind erosion

Erodibility of treated soils was measured in a wind tunnel: In order to create a wind at a specified speed and at a given time, the wind erosion apparatus (a portable wind tunnel that can be used both in the laboratory and on the field) was used. After preparation the treatments, trays were placed inside the tunnel. Wind speeds of 85 km h^{-1} (predominant speed in studied area) was applied to treatments for 20, 40 and 60 minutes. After each time, the amount of the eroded soil from the depository was weighed and data were calculated as $kgm^{-2}h^{-1}$.

2.4. Statistical analysis

This research was performed as a completely randomized design. Statistical analysis of data was done by SPSS software and comparison means was made by LSD test.

3. Results and Discussion

3.1. Chemical and physical properties of soil

The texture of study soil was coarse (loamy sand). The reason for the formation of sand dunes in this area is the high amount of sand (80.56 %). The amount of calcium carbonate was 8.9 % and had no secondary gypsum, pH was 7.81, electrical conductivity was 0.91 dS m^{-1} and soil organic carbon was 0.52 %, which is similar to that of arid soils.

3.2. Analysis of variance

Analysis of variance (Table 3) showed that effect of experimental treatments (mulches) on all studied factors i.e. penetration resistance, crust thickness, abrasion resistance, and impact resistance were significant at $P < 0.01$.

Table 3. Results of analysis variance for different factors

Sources of variation	Degree of freedom	Sum of square						
		penetration resistance ($kgcm^{-2}$)	Crust thickness (mm)	Abrasion resistance (-)	impact resistance (-)	Soil erosion in 20 minute (gm^{-2})	Soil erosin in 40 minute (gm^{-2})	Soil erosion in 60 minute (gm^{-2})
treatments	7	0.6393**	0.6144**	0.1818**	0.2384**	97454.1**	6730024**	12806957**
error	16	0.0001	0.0003	0.0005	0.0006	52	70	100.78
Coefficient of variation (CV)	-	31.96	28.1	42.26	49.02	196.07	200.92	185.76

3.3. Penetration resistance

Application of mulches increased the penetration resistance compared to the control and except for Z2 and R1 all treatments had significant differences with each other. Control treatment (0.546 kg cm^{-2}) had the least resistance and the 10 gram of resin (R2) (1.756 kg cm^{-2}) and 200 g of bentonite (B2) (1.710 kg cm^{-2}) had the highest values of penetration resistance (Table 4). These two treatments increased the penetration resistance up to 3.13 and 3.21 times compared to the control, respectively (Table 4). The order of penetration resistance was control < cement < Z1 < B1 < Z2= R1 < B2 < R2. When the rate of zeolite, bentonite and resin increased, the penetration resistance cement significantly increased at $P < 0.05$ (Table 4).

3.4. Crust thickness

According to Table 2, the lowest amount of crust thickness (0.463 mm) was found in control and the highest value (1.846 mm) was obtained in R2. This treatment increased crust thickness up to 3.98 times more than the control. Similar to the penetration resistance, although cement mulch had the lowest effect on crust thickness, it increased crust thickness up to 3.84 times compared to the control at $P < 0.05$. Also, the order of crust thickness as same as penetration resistance was control < cement < Z1 < B1 < Z2= R1 < B2 < R2. By increasing the rate of zeolite, bentonite and resin, the crust thickness significantly increased, too (Table 4).

Table 4. Results of mean comparison on investigated factors.

Treatment	Penetration resistance ($kgcm^{-2}$)	Crust thickness (mm)	Abrasion Resistance (Scoring)	Impact resistance (Scoring)
control	0.547 ^{g}	0.463 ^{g}	0.83 ^{f}	0.66 ^{g}
cement	0.787 ^{f}	1.446 ^{f}	0.416 ^{e}	0.216 ^{f}
R1	1.643 ^{c}	1.743 ^{c}	0.775 ^{b}	0.775 ^{b}
R2	1.757 ^{a}	1.846 ^{a}	0.916 ^{a}	0.916 ^{a}
Z1	1.343 ^{e}	1.583 ^{e}	0.550 ^{d}	0.575 ^{d}
Z2	1.643 ^{c}	1.743 ^{c}	0.575 ^{cd}	0.650 ^{c}
B1	1.613 ^{d}	1.706 ^{d}	0.542 ^{d}	0.533 ^{e}
B2	1.710 ^{b}	1.783 ^{b}	0.608 ^{c}	0.675 ^{c}

3.5. Abrasion resistance

Mean comparison of the abrasive resistance based on the scoring technique (Table 1) showed that the lowest abrasive resistance was found in control (0.083) and the highest ones in R2 (0.916) and R1 (0.775) (Table 4). R2 and R1 treatments were classified in the most appropriate class (class 1); while the control treatment was in weakest class (0) because the surface crust was broken with 1-2 times movement of the abrasive sand papers. Cement treatment (0.216) was close to class 0.25. Other treatments were classified in intermediate classes. Also, the comparison of means showed all treatments decreased the score of abrasion resistance significantly compared to the control. In addition, clay mulches had no significant differences, but their differences with other treatments were significant at $P < 0.05$ (Table 4).

3.6. Impact resistance

The results of impact resistance according to the scoring technique, showed that the lowest value of impact resistance was found in control (0.066) and the highest value was observed in R2 (0.916) and R1 (0.775) treatments. These two treatments, and especially R2 were classified as the most suitable class in terms of impact resistance and did not break the surface of soil by dropping the rod, but in the control treatment, which it was in the lowest grade, surface of soil was broken when rod was dropped down and the rod was penetrated up to a depth of 4 centimeters. Other treatments were classified in the middle classes. The comparison of means showed that all treatments decreased the score of impact resistance significantly compared to the control. In addition, except for Z2 and B2, other treatments had significant differences at $P < 0.05$ (Table 4).

3.7. Soil erosion

Based on analysis of variance the effect of mulch, time and interaction effect of them on soil erosion content were significant at $P <0.01$ (Table 5).

Table 5. Analysis of variance for treatments and time on soil erosion.

Source of variances	Degrees of freedom	Sum of squares
Mulch	7	36176074**
Time	2	431244**
Mulch*time	14	273343**
Error	48	242.094

** Significant at $P < 0.01$.

Comparison of means (Table 4) revealed that all treatments significantly reduced the soil erosion content in relation to the control, and Z1, Z2, B1, B2 and R1 treatments had no significant difference (P <0.05). During the first 20 minutes, the highest amount of soil erosion was found in the control (1677.3 g m^{-2}) and the lowest content was found in R2 (0.3 g m^{-2}). According to these results, the highest reduction of soil erosion was obtained in R2, following the R1, B2 and B1 treatments, respectively, which was 511, 91.83, 71.78 and 55 times lower than the control (Fig. 1.). Similarly, during the second 20 minutes, the highest amount of soil erosion was obtained in the control (4380.5 g m^{-2}) and it significantly less than all treatments. The lowest content of soil erosion was found in R2 (21.31 g m^{-2}) and R1 (24.35 g m^{-2}) treatments, which their differences were not significant. Soil erosion during the last 20 minutes was similar to previous times, and control (6054.8 g m^{-2}) had the highest soil erosion and R2 (21.31 g m^{-2}) and R1 (24.35 g m^{-2}) with no significant difference had the least soil erosion. Regard to the results of wind erosion at all three times and considering the no significant difference between the two resin rates, R1 treatment can be considered as the most suitable treatment for controlling wind erosion. However, due to the natural origin of bentonite, environmental favorite and as a fraction of soil particles. In addition, it did not differ significantly from the resin. Therefore, it can be considered as a suitable mulch for controlling wind erosion in areas where wind erosion is a serious problem.

The interaction effect of time and mulches showed that the highest erosion was found in control treatment after 40 minutes (6570.78 g m^{-2} h^{-1}), and it was significantly less than the 20 minutes. It seems that after 40 minutes, most of the soil has been eroded, so it has been decreased during the last 20 minutes in control treatment. The erosion content in cement treatment significantly increased during the time. Soil erosion after 20 minute in Z1 and Z2 significantly decreased compared to the first 20 minute, and there was not any significant difference between 40 and 60 minutes in these treatments. However, the erosion contents in these treatments were considerably more than R1, R2, B1, and B2. There was no significant difference between 20 and 40 minutes in B1, while it significantly increased after 60 minutes, therefore it seems that the efficiency of cement, Z1 and somewhat B1 to reduce the soil erosion decrease during the time. But the erosion rate in B2, R1 and R2 didn't change during the time. Nevertheless, among the studied treatments R2 had the best efficiency to reduce the erosion content (Fig. 1), regard to environmental aspect of these materials and bentonite is a fraction of soil and it can bind soil particles, create large aggregates and increase surface roughness, therefore it seems that B2 may be the best treatment to reduce soil erosion. Application the mulches is one of the important strategies to combat the wind erosion in short time.

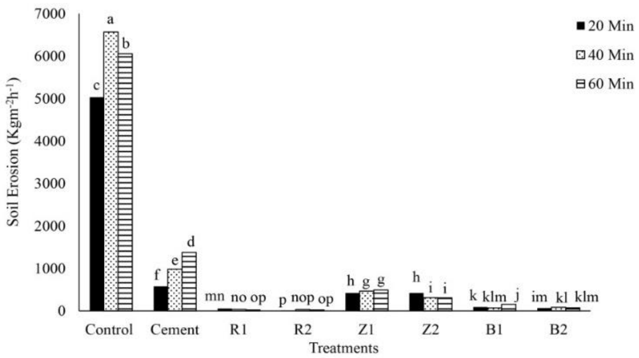

Fig. 1. Comparison means of interaction effects of mulch and time on soil erosion.

Of course, to select the best mulch the environmental conditions should be regarded in this issue. According to our results, all mulches significantly increased the impact, abrasion, and penetration resistances, and the crust thickness, as a result of these wind erosion significantly decreased compared to the control. The greatest thickness of crust on the soil surface reduces soil erosion (Jafari, 2014; Hazirei and Zare Arnani, 2013). Among the treatments, R2 (10 g resin + 1000 ml water) had the best effect on soil stability and increasing resistance against wind speed of 85 km h^{-1}. High efficiency of polymers has been reported by Movahedan et al. (2011). Polyvinyl acetate is one of the organic polymers that can play a significant role in soil conservation. Therefore, it can be said that the advantage of this mulch is its degradability in nature, which is degraded after some time and does not have any adverse environmental effect; while many mulches used to stabilize moving sands cannot be decomposed, or their decomposition is time consuming late and have adverse environmental effects. By comparing the treatments in terms of different factors related to wind erosion, it can be concluded that cement mulch (combined 50 g cement + 100 g sand + 1000 ml water) had the least effect on soil resistance and stability and soil erosion. The results of soil erosion in this study were consistent with the results of Movahedan et al. (2011), and Diouf et al. (1990). They found that usage of mulch increases the soil resistance against wind erosion. Alex and Vino (2016) also introduced the resin as a best mulch to improve soil stabilization. Emami and Astaraei (2012) concluded polyvinyl acetate and gypsum can improve soil structure stability. Despite Miller et al. (2000) introduced cement as a soil stabilizer, but it cannot be the best mulch at least for high wind speed such as 85 km h^{-1}. In this study, increasing the concentration of mulches had a great effect on increasing soil resistance and reducing the wind erosion. Of course, when resin rate increased from 5 to 10 g, soil erosion did not significantly change. In addition, there was a little difference between R2 and B2. Since bentonite is more suitable for reducing environmental hazards and cost effectiveness and it’s a soil fraction and due to environmental favorite in relation to polyvinyl acetate.

4. Conclusion

Combat to wind erosion is most important in arid and semi-arid regions. Therefore, in this study some types of sand stabilizers (cement, Polyvinyl Acetate, zeolite, and bentonite) were compared to determine the most suitable mulch regard to environmental adaptation. According to the results, all mulches significantly increased the impact, abrasion, and penetration resistances, and the crust thickness, as a result of these wind erosion significantly decreased compared to the control. However, cement had the least effect on soil resistance and soil erosion and among the treatments, R2 (10 g Polyvinyl Acetate + 1000 ml water) had the best effect on soil stability and increasing resistance against wind speed of 85 km h^{-1}. Also, there was a little difference between R2 and B2 (200 g bentonite + 1000 ml water) and, due to bentonite mine in Iran, the cost of bentonite is very lower than the resin, therefore B2 can be recommended to stabilize soil particles and to combat wind erosion.

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