Global J. Environ. Sci. Manage. 6(4): 537-552, Autumn 2020

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

CASE STUDY

The effect of mulch on properties of erosion sensitive soil using a wind tunnel

P. Gholamiderami[1], P. Lahooti[*,1], H. Darbam[2]

[1]*Department of Soil Engineering, Faculty of Agriculture, Sari Agricultural Sciences and Natural Resources University, Sari, Iran*

[2]*Department of Construction Engineering. Faculty of Engineering, Yasooj Branch, Islamic Azad University, Yasooj, Iran*

ARTICLE INFO

Article History:
Received 10 November 2019
Revised 23 April 2020
Accepted 11 May 2020

Keywords:
Biochar
Organic mulch
Organo mineral
Wind erosion

ABSTRACT

The aim of this study was to produce mulch by combining natural mineral and organic substances in order to reach soil stabilization and improve soil physical and mechanical properties in Koopal area. The effects of organic mulch (at 3 levels of O1: combination of 1% sugarcane bagasse biochar+0.5% gum Arabic+0.5% gelatin; O2: combination of 3% sugarcane bagasse biochar+1% gum Arabic+1% gelatin; and O3: combination of 5% sugarcane bagasse biochar+1.5% gum Arabic+ 1.5% gelatin) and MNF organomineral mulch (at 3 levels of MNF1: 1%; MNF2: 3%; and MNF3: 5%) on soil were investigated. The soil samples were incubated for 2 and 4 months and finally placed in a wind tunnel. Some physical and chemical properties of soil were obtained as pH=7.42, O.M%=0.223, and soil texture of silty loam. The obtained results showed that compared to control, application of the mulches increased soil organic carbon percentage (1.1%), mean weight diameter (2.47 mm), geometric mean diameter (1.27 mm), penetration resistance (370), shear strength (27.38) and tensile strength (0.8) significantly and decreased soil loss (0.10 g/m2/s), fracture index, soil texture index (62.16), and crust index (1.18) significantly (P<0.01) in both incubation periods. Effects of the mulches on soil organic carbon were reduced after 4 months. In mulch treatments, soil loss rate, mean weight diameter, geometric mean diameter and tensile strength were increased significantly. In general, the organic mulch could stabilize the soil and improve the physical and mechanical properties of the soil.

DOI: 10.22034/gjesm.2020.04.09

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
52	9	3

*Corresponding Author:
Email: *Parisa_lahooti69@yahoo.com*
Phone: +989170196726
Fax: +987433334140

Note: Discussion period for this manuscript open until January 1, 2021 on GJESM website at the "Show Article.

INTRODUCTION

Due to the geographical location of Khuzestan province and arid climate of its neighboring regions, plans for preventing desertification and soil stabilization practices at wind erosion source areas seem to be inevitable. Most parts of Iran are located in arid and extremely arid regions with annual precipitation of less than 150 mm. About 80 million hectares of the country is covered with deserts, sand dunes and areas with sparse vegetation (Abtahi, 2017). The first extensive dust storm in Iran occurred during 2003-2004 and influenced 20 provinces including Khuzestan. Climate change, by causing drought, influencing soil moisture and limiting plants growth, is considered as one of the most important factors involved in deteriorating wind erosion and dust condition in the world (Bazgir and Namdar Khojaste, 2018). Main consequences of wind erosion are air pollution, vision limitation, depreciation of industrial machinery, destruction of soil structure, and decline of soil productivity (Sabzi *et al.,* 2018; Li *et al.,* 2020). In recent years, the increased occurrence of wind erosion and dust phenomenon has deteriorated life quality in some areas of Khuzestan province. Therefore, researchers seek to identify critical wind erosion areas and propose more appropriate methods to control these areas. Application of mulch is known as an appropriate strategy for soil stabilization and soil erosion prevention. Generally, a natural or artificial substance which covers soil surface, contributes to better soil quality and protects it against erosive agents is called mulch (Kazemi and Safaria, 2018; Jefline *et al.,* 2020). Mulch can protect soil particles against erosive agents, especially wind, by creating cohesivity. Depending on type of constituents, mulches can be classified into organic mulches made of chopped tree barks, sawdust, straw (from plants such as barely), composted manures, agricultural products, shredded grass, etc., and inorganic mulches made of brickbats, rubber pieces, decomposed granite, different types of stone and gravel, polyethylene, and pea gravels (Steward *et al.,* 2003; Bunna *et al.,* 2011). Application of mulch can lead to increase of soil water retention capacity, stimulation of soil biological activity, reduction of soil erosion, improvement of soil organic matter (SOM) and aggregate stability (Yang *et al.,* 2020; Li *et al.,* 2018). Therefore, use of organic materials for soil conservation has an important role in enhancing erosion threshold velocity. Biochar is a porous dark material produced from organic biomasses during pyrolysis process and is highly stable against decomposition. Biochar, as a soil amendment, can increase the mean weight diameter (MWD) of soil aggregate and decrease the amount of soil loss (Lehmann *et al.,* 2006). Gum Arabic is a natural polymer with high molecular weight, calcium, magnesium and potassium salts and is a complex mixture of polysaccharides and glycoproteins. Gum Arabic is more available and cheaper than other artificial synthetic polymers. It can be provided as powder or emulsion and be added to soil individually or in combination with other soil amendments. Stickiness and jelly-like nature of gum Arabic can be effective in binding soil particles together and creating a more stable soil structure (BeMiller and Whistler, 2012; Whistler and Hymowitz, 1979). Tensile strength of soil aggregates is one of the most important factors in evaluating aggregate consistency which is used as an index for aggregate resistance against erosive agents (Dexter and Kroesbergen, 1985). Aggregate tensile strength stems from soil organic matter and its structural characteristics and is influenced by aggregate porosity arrangement (Hallett *et al.,* 1995). MWD of aggregates is an index for aggregate stability and soil erodibility (Ouyang *et al.,* 2013). Application of biochar as organic treatment increases soil porosity and MWD and improves soil structure which finally decreases soil erodibility and soil loss (Khademalrasoul *et al.,* 2014; Ouyang *et al.,* 2013). Bayamont *et al.* (2019) studied the effect of biochar (made of forest tree branches biomass) on sandy soil and observed that it improved aggregation, surface area and soil porosity. Abtahi (2017) studied the effect of cellulose polymer mulch (CPM) on sand stabilization. He measured erodability index in wind tunnel, compressive strength, abrasion resistance, impact resistance and thickness of the layers produced by using solutions with different CPM doses. He obtained the highest impact strength and the lowest soil erodibility index by applying a solution containing 30% CPM and 70% water, and proved that CPM has a positive effect on plant establishment. The present study has been conducted to highlight the high importance of evaluating different mulches for improving the properties of erodible soils and sustainable management of organic residues. The aim of this study was to produce recombinant synthetic mulches by combining natural mineral and organic substances with new compounds, in order to reach soil stabilization and improve soil physical and mechanical properties. Literature review indicates that a few studies yet have considered the effect of these parameters on soil properties and soil erodibility. This clearly emphasize the importance of the present study. This study has been carried out in Koopal at the southeast of Ahwaz in 2019.

MATERIALS AND METHODS

Study area

The study area, with an area of about 20 ha, is located at the south-eastern part of Ahwaz in Koopal. It lies between longitude of 48°, 50', 22.65" to 48°, 50', 64.65" E and latitude of 31°, 06', 20.64" to 31°, 07', 3.14" N in an altitude of 11 m above mean sea level (AMSL) (Fig. 1). This area contains alluvial plains with high erodibility and soil texture of mostly silty loam (SiL). Vegetation of the area is weak coverage of halophyte bushes like Halocnemum strobilaceum. Meteorological information of the study area was obtained from Ahwaz weather station (Table 1). Moreover, the annual wind rise records obtained from Ahwaz weather station are presented in Fig. 2 (khosravi *et al.,* 2016).

Mulch synthesis and evaluation in laboratory (small-scale)

Before selecting the best mulch, the organic and mineral materials were investigated individually, as combination of two materials, and as combination of three of materials. The purpose of such investigation was to determine whether the materials have high viscosity, high water absorption capacity and high cohesivity and adhesivity. Soil covering with the optimal selected levels were applied in erosive plots with length of 1.5 m, width of 2 m and depth of 5 cm in specific sampling sites (Abtahi, 2017). Afterwards, the observed changes in the added mulches were evaluated during 2-month and 4-month periods. The optimal results were obtained using organic mulch (at 3 levels of O_1: combination of 1% sugarcane bagasse biochar+ 0.5% gum Arabic+ 0.5% gelatin; O_2: combination of 3% sugarcane bagasse biochar+ 1% gum Arabic+ 1% gelatin; O_3: combination of 5% sugarcane bagasse biochar+ 1.5% gum Arabic+ 1.5% gelatin) and MNF organomineral mulch (at 3 levels of MNF_1: 1%; MNF_2: 3%; MNF_3: 5%). To preparing the sugarcane bagasse biochar, the dried biomasses were placed in the galvanized iron metal boxes coated with replaceable thin aluminum sheets. The dimensions of the boxes were matched with the furnace space.

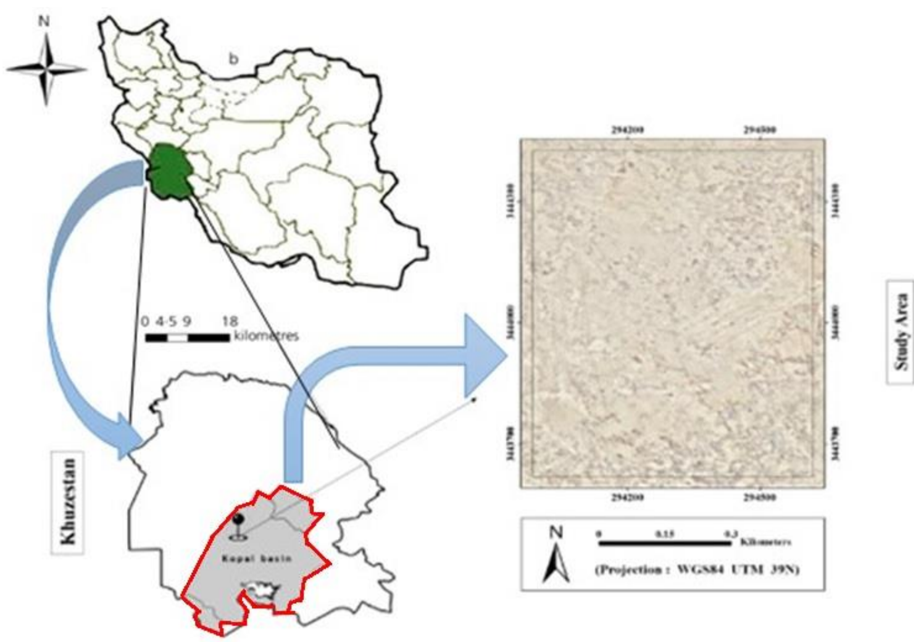

Fig. 1: Geographical location of the study area in the south-eastern part of Ahwaz in Koopal, Iran

Table 1: Meteorological information of the study area (2014- 2019)

Parameters	Values
Absolute maximum temperature (°C)	51.5
Absolute minimum temperature (°C)	2.26
Mean temperature (°C)	27.08
Mean maximum temperature (°C)	34.28
Mean minimum temperature (°C)	19.84
Precipitation (mm)	190.82
Transpiration (mm)	2944.12
Maximum wind speed ($m.s^{-1}$)	20
Direction of the first prevailing wind	West to northwest
Direction of the second prevailing wind	West

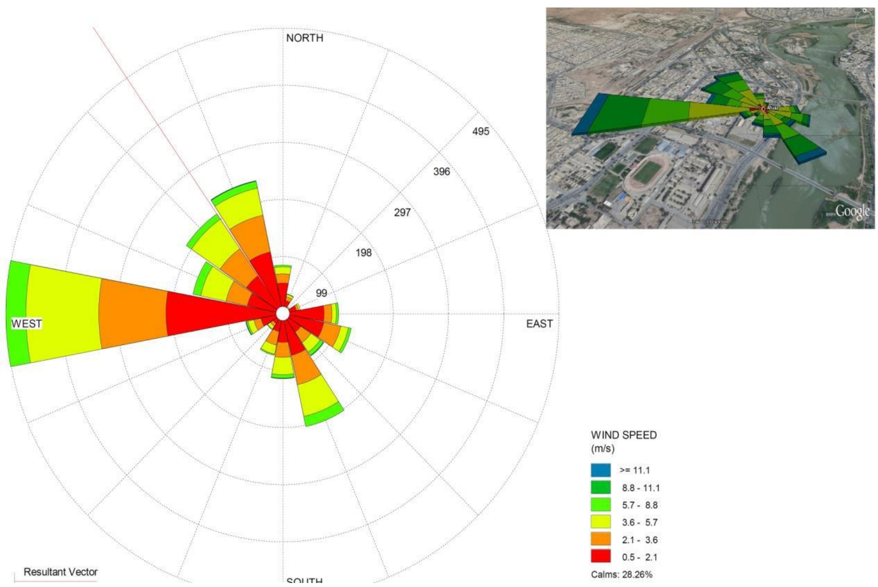

Fig. 2: Annual wind rise records obtained from Ahvaz weather station

In order to evacuate air from the samples, they were fully compressed using a 10 kg weight. In addition, the materials in the boxes were covered with aluminum sheets. Then, the boxes lids were closed and the boxes were placed in a Muffle Furnace (SEF-101, Fine Tech ltd.). Thermolysis process of the samples was performed in a 400 °C furnace for 3 hours with temperature increase rate of 7 °C/min. MNF is a natural powdery white-colored substance mainly composed of gypsum, cellulose and small amounts of clay. The MNF used in this study was obtained from Sanat Sazeh Satrap factory.

Soil sampling

Sampling was done observationally via field visit method, in which soil samples were collected from three points with known slopes. Ignoring the vegetation, sampling depth was 0-15 cm.

Measurement of the physical and chemical parameters of soil and mulches

Soil samples were air-dried and then transferred to the laboratory. Afterwards, soil organic matter (SOM) was measured by Walkley-Black method (Walkley and Black, 1934), pH was determined at 1:2 ratio using a pH-meter (Mclean, 1982), soil electrical conductivity (EC) was measured using an EC-meter (Roads, 1986), soil lime (calcium carbonate) amount was measured by back- titration method (Klute, 1986), field capacity (FC) was measured using pressure plate instrument, soil bulk density was determined with the help of metallic sampling cylinder (Klute and Dirksen, 1986), soil particle density was determined by pycnometer method, and exchange capacity (CEC) was measured via ammonium acetate method (Sumner and Miller, 1996). Soil texture was examined by hydrometry method and the texture class was determined using soil texture triangle (Bouyoucos, 1962). To determine the chemical properties of bagasse biochar, the samples were sieved through a 2-mm sieve and gum Arabic and gelatin were powdered.

Laboratory experiments

Experiments were carried out in galvanized iron plots (50×30×5 cm^3). The soil added to each plot was calculated using bulk density of control. Moreover, it was weighted and its moisture was set to 75% FC. The determined levels of mulches were uniformly mixed with soil and incubated for 2 months and 4 months. During these periods, soil moisture was maintained at 75% FC. At the end of incubation periods, aggregate stability was measured according to MWD using Eq. 1 (Van Bavel, 1950), geometric mean diameter (GMD) was measured using Eq. 2 (Pinheiro *et al.,* 2004), penetration resistance (PR) was measured using manual penetrometer device, soil tensile strength (TS) was measured by indirect Brazilian test (IBT) (Eqs. 3 and 4), soil shear tension (ST) was calculated using shear-blade device (CL 100), friability index (FI) was measured using Eq. 5, crust index (CI) was obtained using Eq. 6 (Pagliai, 2007) and soil texture index (STI) was determined using Eq. 7 (Bélanger, 2000).

$$MDW = \sum_{i=1}^{n} \overline{Xi}Wi \quad (1)$$

Where, $\overline{Xi}$ is mean diameter of aggregates for any particular size range; W_i is weight of the aggregates in a size range as a fraction of the total dry weight of the sample; and n is the number of sieves.

$$GMD = \exp\frac{\sum_{i=1}^{n} WiLog\overline{Xi}}{\sum_{i=1}^{n} Wi} \quad (2)$$

Where, W_i is weight of the aggregates in a size range of average diameter X_i; and ∑ is total weight of the soil sample.

$$Y = 0/576\frac{F}{d_{eff}^2} \quad (3)$$

Where, F is the compressive force required for breaking aggregates with effective diameter of d_{eff}; and Y is soil TS. Aggregated effective diameter can be calculated using Eq. 4 (Dexter and Kroesbergen, 1985).

$$d_{eff} = d_0\frac{M_a^{0/3}}{M_0} \quad (4)$$

Where, d_{eff} is aggregate effective diameter; d_0 and M_0 are average diameter and average mass of 30 soil aggregates, respectively; and M_a is mass of the considered aggregate (Dexter and Kroesbergen, 1985).

$$F = \frac{\sigma Y}{\overline{Y}} \pm \frac{\sigma Y}{\overline{Y}\sqrt{2n}} \quad (5)$$

Where, FI indicates soil friability; σY is standard deviation of TS; $\overline{Y}$ is the measured TS; and n is the number of aggregates (Dexter and Kroesbergen, 1985).

$$CI = \frac{1.5(\%FineSilt) + 0.75(\%Coarsesilt)}{Clay + 10(\%Organicmatter)} \quad (6)$$

$$STI = \frac{1.76 \times \%O.C}{0.03 \times \%Sand + 0.022 \times \%Silt + 0.08 \times \%Clay} \times 100 \quad (7)$$

Wind tunnel test was used to study the erodibility of the samples. Wind tunnel components are fan-jet (a device to uniformize air distribution), body and a bag at one end to collect the soil detached from soil surface. The device body, with a dimension of 900×70×70 cm^3, can generate wind with the velocity of 10-110 km/h. Device's motor power was 18.5 kW with rotation speed of 2900 rpm. The device was equipped with a 70-cm canal turbojet airway and a 10-blade propeller at 45° angle with a 6-blade motor cooling shaft installed in a cabinet. Considering the maximum wind speed in the study area, a wind with a speed of 20 m/s was generated at the tunnel central axis 15 cm above the soil surface. Soil sample trays were weighted before entering the wind tunnel and reweighted after being exposed to a 20-m/s wind in the tunnel for 10 m. Using the difference between the primary and secondary weights of the sample trays, the weight of the soil harvested from the soil surface was determined and measured as the amount of wind erosion.

Statistical analysis

The data collected from the experiments were subjected to analysis of variance using SPSS software, and Duncan's test at 5% probability was selected as the mean comparison test. Finally, the best combination with lowest erodibility was selected and applied in erosion plots. This study was carried out as a factorial design in the form of completely randomized blocks.

Table 2: Physical and chemical properties of the studied soil

Properties	Values
pH (1:2)	7.42
EC (ds/m)	66.8
CEC (cmol/kg)	44.07
Bulk density	1.42
Calcium carbonate (%)	42.4
O.M (%)	0.223
Silt (%)	66
Sand (%)	16.26
Clay (%)	17.74

RESULTS AND DISCUSSION

Physical and chemical properties of the studied soil and mulches are presented in Tables 2 and 3 respectively. Properties of the studied soil were obtained as pH=7.42, O.M%=0.223, and soil texture of silty loam. The highest and the lowest pH values of 10.3 and 5.48 were observed in sugarcane bagasse biochar mulch and gelatin mulch, respectively (Table 3).

Statistical analysis

Effects of 2-month and 4-month incubation periods on the measured parameters

Figs. 3-6 indicate the effects of mulch type and application rate (level) on soil organic carbon content, soil loss, MWD, GMD, CI, STI, FI, shear strength (Shs), PR and TS of soil aggregates in the two incubation periods (2-month and 4-month). O_3 and MNF_3 mulches had the highest rate of interaction with soil O.M% in the treatments in both incubation periods (2-month: 1.01% and 0.66%, respectively; 4-month: 0.97% and 0.58%, respectively) (Fig. 3). Soil organic carbon is an important indicator of soil quality and soil health. Conservation tillage reduces soil disturbance and slows mineralization of soil organic matter (Liu *et al.,* 2014). Properties of mulches depend on the properties of their biomass type. Organic mulch, because of its higher O.M content, improved soil physical and mechanical properties and aggregate stability. Therefore, it can be concluded that higher contents of gum Arabia, gelatin, sugarcane bagasse biochar and MNF mulches lead to higher O.M content. Li *et al.* (2018) and Yang *et al.* (2020) reported that adding mulches, by increasing soil organic matter and aggregate stability, leads to less soil erosion. Hosseini Bai *et al.* (2013) incorporated the organic matter of forest mulch into the soil to improve organic matter content and therefore the ability to retain moisture compared to the soil with lower organic matter content. This indicates the positive effect of organic matter on aggregate stability. Li *et al.* (2020); Dong *et al.* (2019); Chen *et al.* (2018) and Zhang *et al.* (2019) obtained the same results. It should be noted that effectiveness of the treatments was changed with time and decreased compared to 2-month period. However, the effect of organic treatments on soil properties depends on their O.M%. The highest soil loss in both incubation periods was observed in control (without mulch). In other treatments, the used mulch decreased the soil loss content significantly. O_3 and MNF_3 treatments with the two mulch types had the highest effect on soil loss reduction (2-month: 0.10 and 0.12 g/m2/s, respectively; 4-month: 0.10 and 0.15 g/m2/s, respectively) (Fig. 3). Mulch binds with the soil mineral components and covers soil surface to protect soil particles against detachment by wind and decrease soil loss (Lohrasbi *et al,* 2019). Briggs *et al.* (2005) reported that bio-coal, due to its high carbon content, could form hydrocarbon chains at the soil surface and induce hydrophobic property on the soil surface. Li *et al.* (2020) and Bazgir and Namdar

Table 3: Physical and chemical properties of the studied mulches

Properties	Sugarcane bagasse biochar	MNF mulch	Gum Arabic	Gelatin
pH (1:20)	10.03	8.32	5.89	5.48
EC (µs) (1:20)	1273	1051	384	955
CEC (cmol/kg)	27.38			

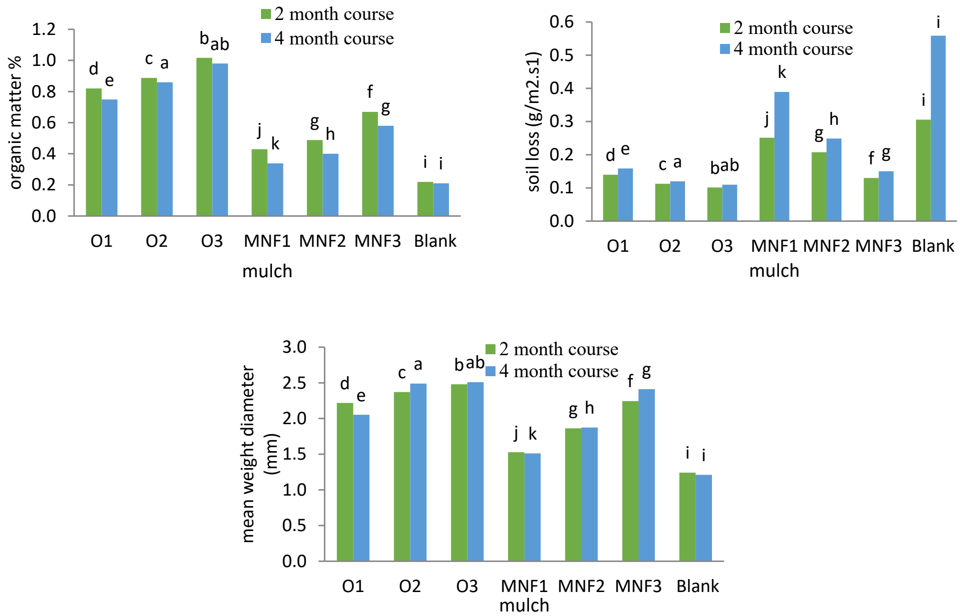

Fig. 3: Interactions between mulch types and their application rates on soil organic matter content, soil loss and mean weight diameter of soil aggregates for the two incubation periods (2 and 4 months)
Numbers followed by the same letter in each row have no significant differences (P<0.05)

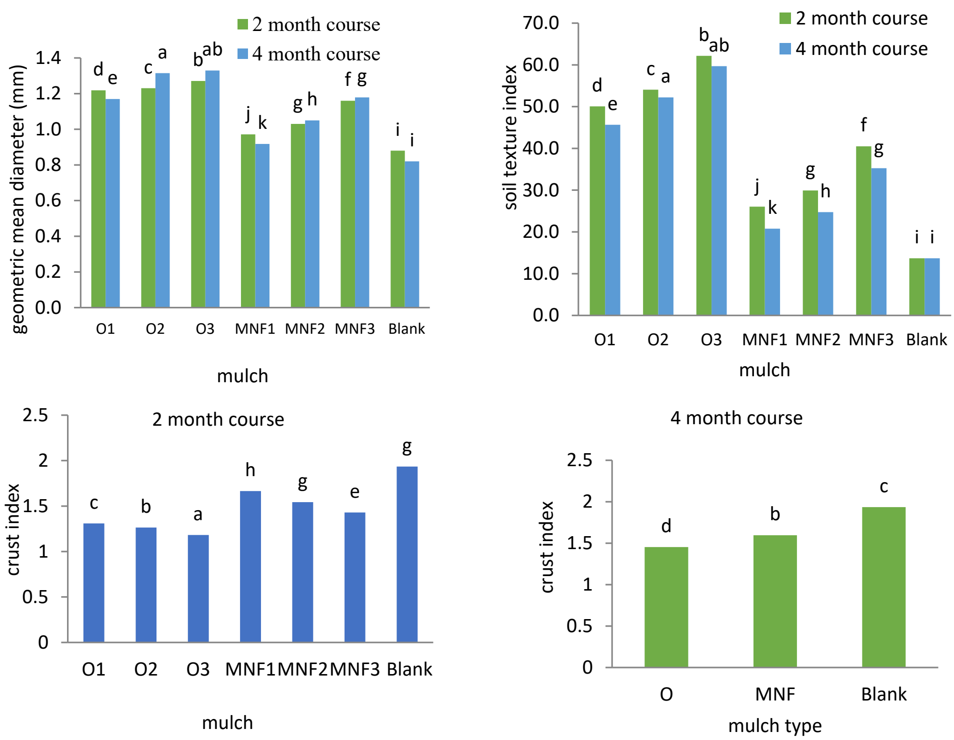

Fig. 4: Interaction between mulch type and their application rates on geometric mean diameter, soil texture index and crust index for the two incubation periods
Numbers followed by the same letter in each row have no significant differences (P<0.05)

Khojaste (2018) obtained the same results and expressed that mulch addition to soil increased soil organic carbon content and decreased soil loss. In both 2-month and 4-month incubation periods, O_3 treatment had the largest influence on MWD (2-month: 2.47 mm; 4-month: 2.50 mm) (Fig. 3) and GMD (2-month: 1.27 mm; 4-month: 1.32 mm) (Fig. 4). Generally, organic treatments had better effects on MWD and GMD. Organic matter, by having hydrophobicity and increasing adhesion between soil particles and finally creating a coherent layer of large aggregates on soil surface, increases soil MWD and GMD. This mulch plays an important role by acting 1) as a physical barrier to protect aggregates against compression induced by flows, and 2) as a core for generating organomineral bonds. Higher MWD resulted in better soil stability (Castro Filho *et al*, 2002). Karami *et al.* (2012) reported a significant increase in GMD and MWD with the increase of organic residue content. Application of organic amendments contributes to better aggregate stability, water permeability in soil, aeration, and porosity. The results obtained in the present study are in agreement with findings of Bazgir and Namdar Khojaste (2018). Mbagwu and Bazzoffi (1989) found that soil erosion increased by reducing the amount of soil organic matter and the soil became impermeable. In 2-month and 4-month incubation periods, mulch application decreased soil CI significantly, which was more evident in organic mulch treatments (2-month: 1.18; 4-month: 1.45) (Fig. 4). High organic matter in soil creates organomineral complexes and thereby improves soil structure. This, in fact, decreases the soil bulk density, which prevents soil crusting. Lahooti *et al.* (2018) found that higher soil organic matter induced better soil physical properties and consequently reduced soil erosion. In 2-month and 4-month incubation periods, mulch application increased soil STI, with the highest value belonging to O_3 treatment (2-month: 62.16; 4-month: 59.68) (Fig. 5). Lohrasbi *et al.* (2019) reported higher soil texture indices with the increase of soil organic matter. In 2-month and 4-month incubation periods, mulch application increased soil PR and Shs, with the highest

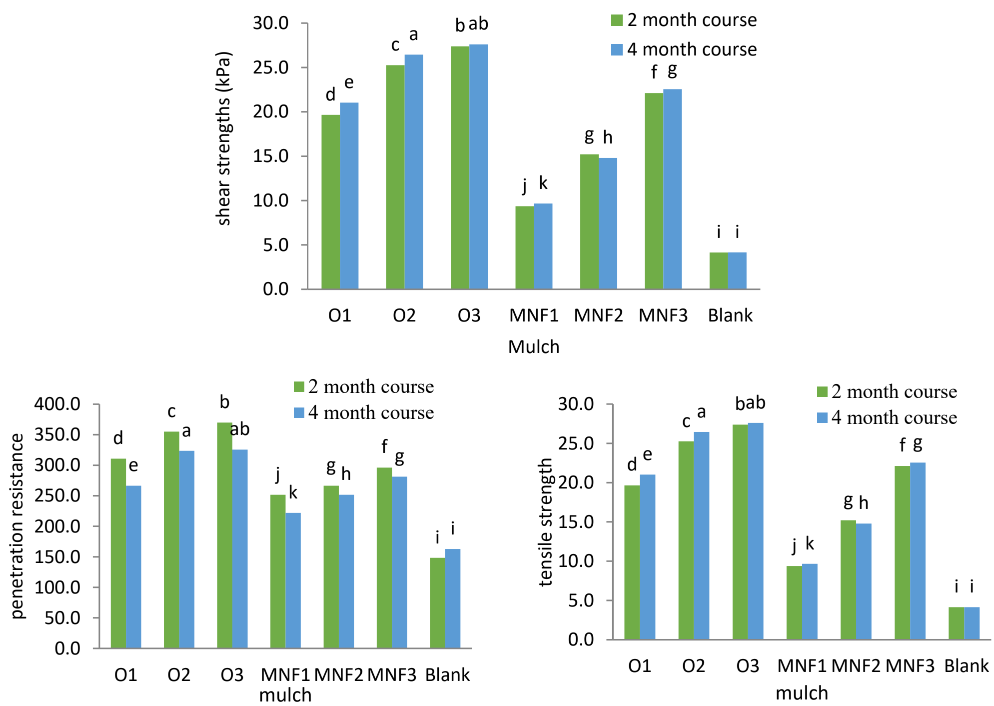

Fig. 5: Interaction between mulch type and their application levels on soil shear strength, penetration resistance, and tensile strength for the two incubation periods

Numbers followed by the same letter in each row have no significant differences (P<0.05)

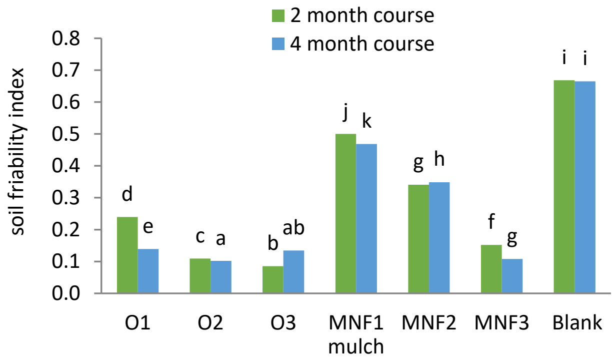

Fig. 6: Interaction diagram of mulch type and its application rates with soil friability index for 2-months and 4-months incubation periods
Numbers followed by the same letter in each row have no significant differences (P<0.05)

value belonging to O_3 (PR: 2-month: 370.001; 4-month: 325.55) (Shs: 2-month: 27.38; 4-month: 27.60) treatment and the lowest value belonging to MNF_1 treatment (Fig. 5). Compared to control, bonding and cohesive agents in mulch composition increased soil Shs and PR, which resulted in less amounts of eroded soil. Due to high silt content in the studied soils, soil particles were loosely joined and soil resistance was weak. Therefore, application of mulches, by creating physical and mechanical bonds between soil and mulch particles, increased cohesivity between single particles, generated a coherent layer and increased soil Shs. Khalili Moghadam *et al.* (2015) reported that increase of the fraction of sugarcane residues significantly increased the Shs of surface soil and PR. Higher concentrations of organic matter, $CaCO_3$, and electrolyte in the sugarcane mulches may have helped the bonding of soil particles and increased the Shs of surface soil and PR. However, the oil mulch had the lowest Shs of surface soil and the highest PR. This might be due to the lower viscosity of oil mulch that allows it to penetrate sand dunes more easily than sugarcane mulches. Sabzi *et al.* (2018) claimed that higher amounts of organic matter and clay increased the compressive resistance, and considered 100 g Dunder plus 100 g Clay as the best composition of organic mulch for stabilization of sand dunes. Naghizade Asl *et al.* (2019) reported that mixing 10% micro-silica with the clay and gypsum added to the soil, increased soil Shs from 10.6% to 37.5% and friction velocity threshold from 45.2% to 48.5% and decreased soil loss. These results are in contrast with the results reported by Lohrasbi *et al.* (2019) and Busscher *et al.* (2010). TS was increased and organic mulches showed better results following mulch application (O_3: 2-month: 27.37; 4-month: 27.59). TS increase can be due to higher soil organic matter as a result of mulch application and improved soil structure and TS. Structural characteristics of the sugarcane bagasse mulch could be also effective in this increase. Lohrasbi *et al.* (2019) indicated that application of the sugarcane bagasse biochar mulch to soil could increase soil TS. In 2-month and 4-month incubation periods, mulch application decreased soil FI, with the highest decrease belonging to O_3 treatment (2-month: 0.8; 4-month: 0.13) (Fig. 6). FI was found to be under the influence of soil TS. According to soil friability classification, soils with FI values less than 0.05 are non-friable, soils with FI range of 0.05-0.1 are slightly friable, soils with FI range of 0.1-0.25 are friable, soils with FI range of 0.25-0.4 are highly friable and soils with FI values more than 0.4 are physically loose and instable (Utomo and Dexter, 1981). Abtahi (2017) reported that biopolymers make aggregates coarser and increase aggregate stability. Lohrasbi *et al.* (2019) found that higher aggregate stability (irrespective of its size) results in higher resistance against erosive agents which prevent dust generation. In addition, higher organic matter in soil creates organo-mineral complexes which produce more stable aggregates, increase MWD and as a result, reduces FI. The impact of mulch type on mechanical properties of soil, such as compaction, unconfined compressive strength (Janalizadeh Choobbasti *et al.*, 2015) and penetration resistance (Baumhardt *et al.*, 2004) has been studied to confirm firstly the improvement of the aforementioned characteristics and secondly wind erosion control. Ouyang *et al.* (2013) stated that adding biochar improves the process of soil aggregation, increases soil permeability and ultimately reduces soil erosion. Yang *et al.* (2020) and Li *et al.* (2018) found that application of mulch could lead to increase of soil water retention capacity, stimulation of soil biological activity, reduction of soil erosion, improvement of soil organic matter (SOM) and aggregate stability. Results of the present study showed that after 4 months the soil had worse properties compared to the 2-month period. This could be attributed to the activity of microorganisms.

Statistical analysis of the effects of mulch type

Figs. 7 to 9 indicate the effects of mulch type, its application level (rate) and incubation period on soil O.M content, soil loss, MWD, GMD, CI, STI, FI, Shs, PR and TS. The highest interaction between mulch type and mulch application levels was related to O.M% (2-month: 0.91% and 0.66%; 4-month: 0.86%). Moreover, O treatment was found to have the highest decreasing effect on soil loss in 2-month and 4-month incubation periods (Fig. 7). Jiang *et al.* (2012) studied the plots treated with biochar and

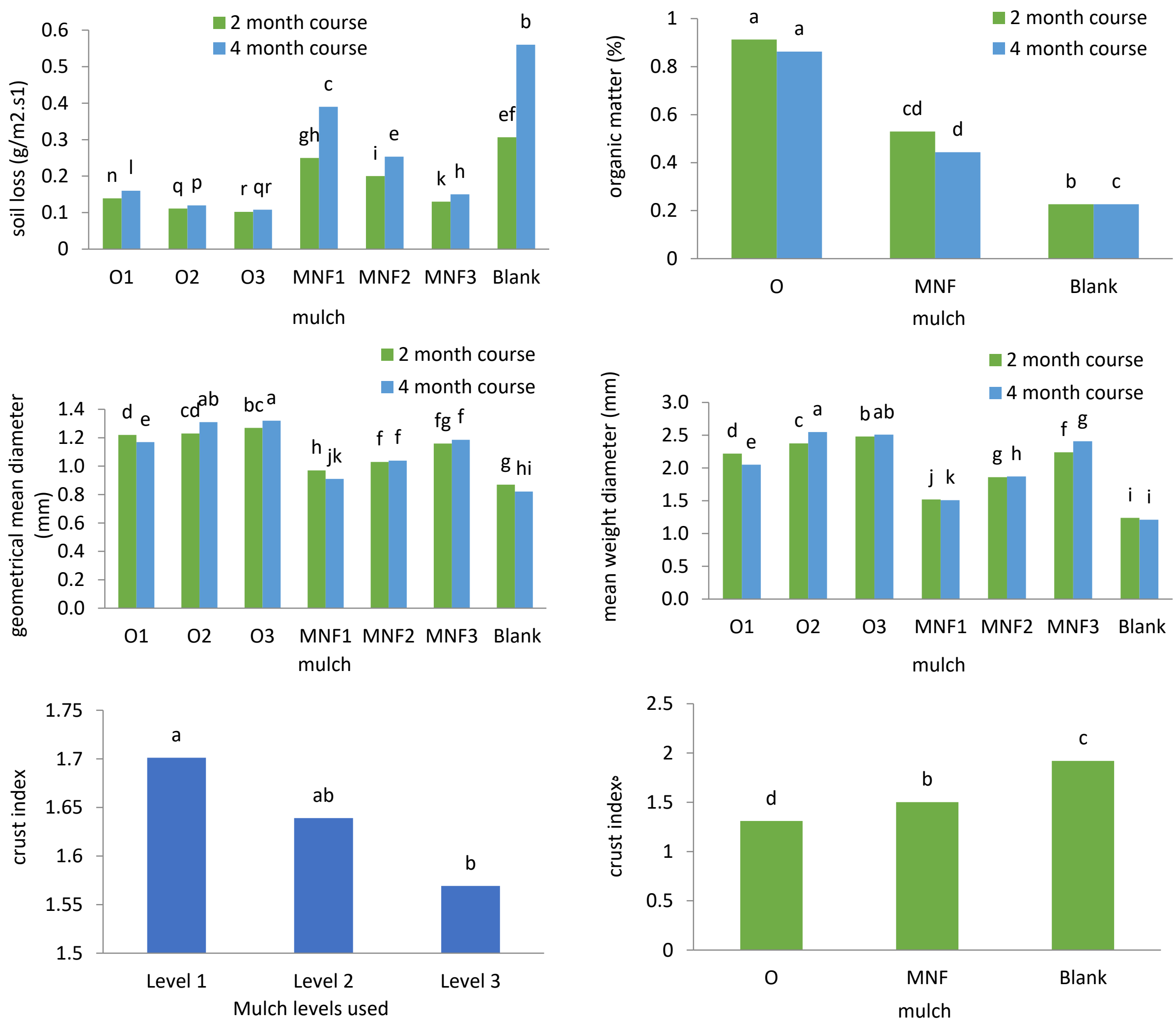

Fig. 7: The effect of mulch type and its application period on soil organic carbon content, lost soil amount, MWD, GMD, and crust index
Numbers followed by the same letter in each row have no significant differences (P<0.05)

concluded that applying biochar to soil increased the soil O.M%. This finding is consistent with results obtained in the present study. Treatments with O mulch amendments had a better effect on soil MWD and GMD (Fig. 7). Results of the present study suggest that adding organic matter to soil decreases the soil CI significantly (Fig. 7). Results of the present study suggest that adding organic matter to soil decreases the soil CI significantly (Fig. 7). Organic matter, by creating organomineral matrices, decreased soil bulk density, improved soil structure and reduced soil CI. Comparison of the effects of treatments on CI revealed that O mulch treatment had the largest effect, because organic matter, as a soil modifying treatment, could reduce soil CI and its degradation (1.31). Organomineral mulches of O had a little effect on increasing soil organic matter, because they consisted of two organic and mineral components. STI was affected by the amount of organic carbon added to the soil. As previously mentioned, STI increases with the increase of soil organic carbon content (Fig. 8). Addition of mulch decreased soil crusting, and the highest level of such decrease was observed in O mulch treatment. Mulch application increased soil Shs and PR in treatments for 2-month and 4 month (Fig. 8). Addition of mulch decreased soil crusting, and

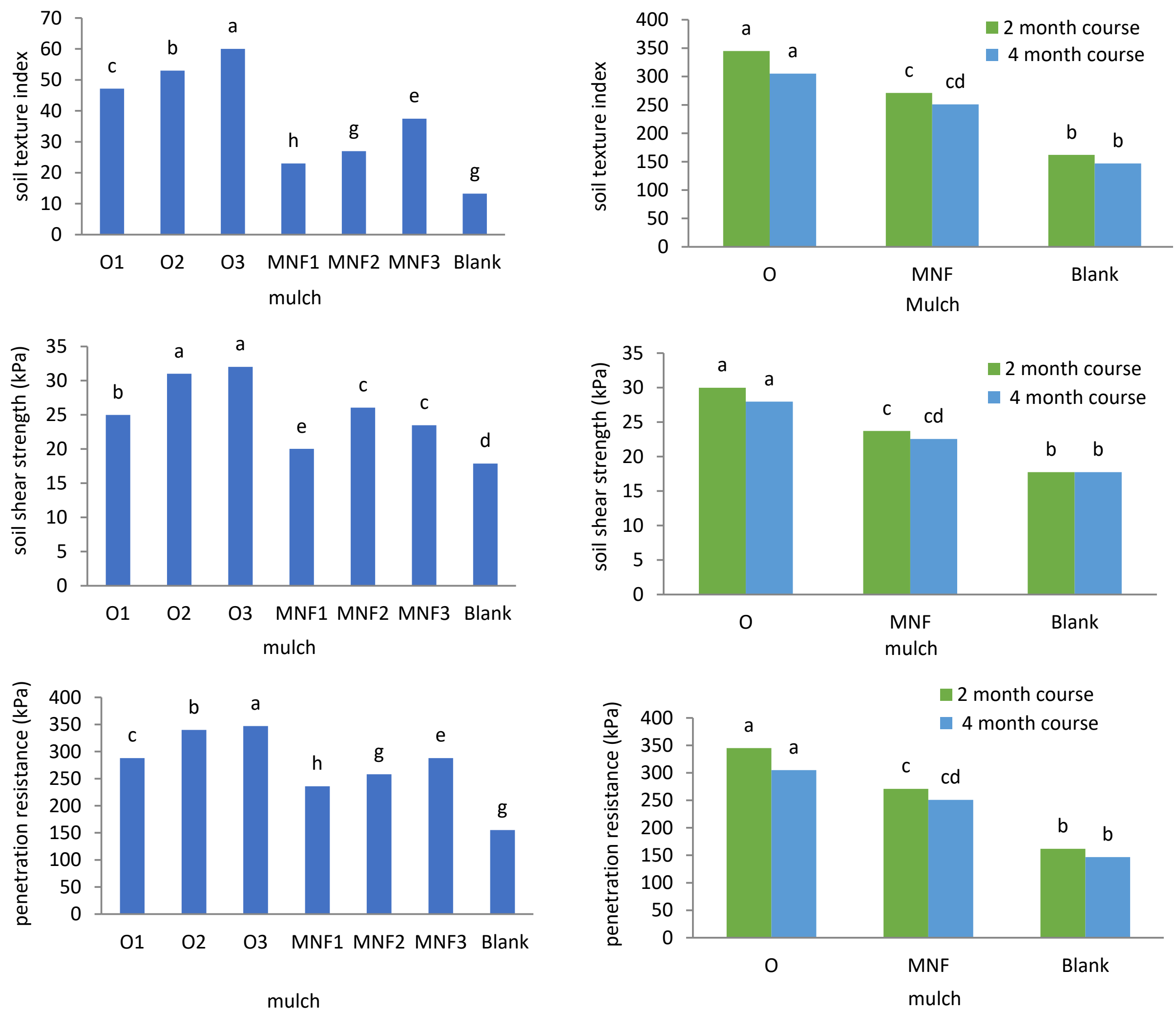

Fig. 8: Interaction between mulch type and its application rate and soil texture index, shear strength and penetration resistance
Numbers followed by the same letter in each row have no significant differences (P<0.05)

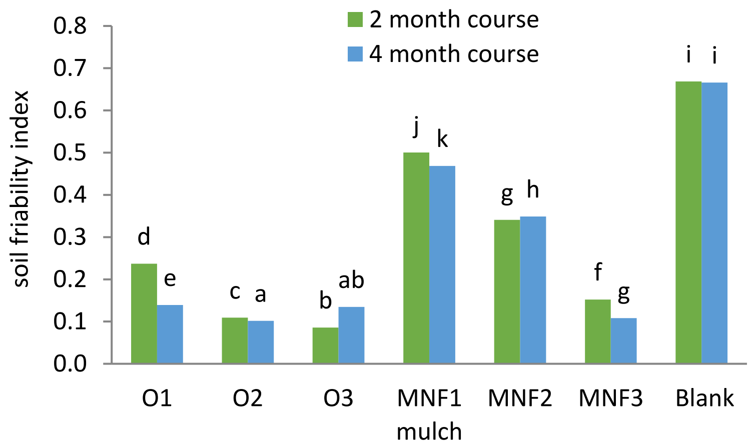

Fig. 9: Interaction between mulch type and its application rate and soil friability index
Numbers followed by the same letter in each row have no significant differences (P<0.05)

the highest level of such decrease was observed in O mulch treatment. Mulch application increased soil Shs and PR in treatments for 2-month and 4 month (Fig. 8). Soil cohesion can influence soil resistance against detachment. Increase of soil cohesion can increase the effects of individual particles and Shs of cohesive soil on soil particle detachment (Wang *et al,* 2001). Shs increased with the increase of mulch application rates (levels) and the highest value was recorded in organic mulch treatment (O_3). Adding mulch decreased the soil FI in the samples incubated for 2 and 4 months periods and the most significant decrease was observed in O_3 treatment (Fig. 8). Organic matter and bonding agents in the mulches can bind mineral and organic components and create organomineral complexes which result in more stable aggregates. On the other hand, organomineral complexes increase soil TS and decrease soil FI. Except for O_3 and MNF_2 treatments, soil FI was decreased in all treatments after 4 months (Fig. 9). FI, which is known to be dependent on TS amount, affects erodibility and dust production potential. Resistance of failure zones is influenced by air-filled pores, micro-pores and bonds between particles or pores (Dexter and Kroesbergen, 1985). This parameter is sensitive to soil structure which depends on soil organic matter condition. Khademalrasoul *et al.* (2014) added biochar and animal amendments to a light-textured soil and found that organic treatments improved soil structural properties and increased soil Shs. Organomineral mulches, however, had an important role in increasing soil water retention capacity. Results of treatments for 2-month and 4-month indicated that Shs value was higher in O mulch treatment than in M mulch treatment. Compared to control, increase of mulch application rate (level) significantly increased Shs. Generally, addition of organic and organomineral mulches to soil improved the soil physical and mechanical properties which could affect soil loss, and therefore decrease soil wind erosion significantly. In 2-month and 4-month incubation periods, O mulch treatment had the largest effect on soil loss reduction (g). In addition, increase of mulch application rate reduced the soil loss, compared to control. This reduction can be attributed to the soil organic matter increase and the improved soil structure and aggregate stability. Furthermore, gum Arabic with its high viscosity and water retention capacity, and gelatin with its ability to bond soil particles, increase soil resistance, especially at soil surface, to reduce soil loss. MNF mulch, with cellulose and bivalent calcium cations, improved soil aggregation condition and its resistance against wind erosion. In the samples incubated for 4 months, soil O.M%, soil surface Shs and surface stability were reduced, compared to the samples incubated for 2 months, so that increase of mulch application rates led to increase of soil loss. The highest resistance against erosion was attributed to O_3 treatment for 2 months, and the lowest resistance against erosion was related to control and MNF_1 treatments for 4 months. In Brazil, Da Silva (2010) applied poly-acrylamide and gypsum to the soil surface in order to reduce the dust generated from soil and silt particles in erosion-sensitive soils and to increase resistance to soil loss. Sterk and Spaan (1997) reported that 1500 kg ha-1 mulch cover reduced sediment transport from 49.7 to 80.2% during five storms with the wind speeds of 8.3 to 10.6 m/s, and therefore recommended it as the best application rate for wind erosion control in Sahel.

CONCLUSION

The objective of this study was to produce recombinant synthetic mulches made of natural organic and mineral substances in combination with new substances and to apply them in Koopal wind erosion area for 2-month and 4-month periods. According to the results, compared to control, application of the prepared mulches increased soil organic carbon percentage (1.1%), mean weight diameter (2.47 mm), geometric mean diameter (1.27 mm), penetration resistance (370), shear strength (27.38) and tensile strength (0.8) significantly and decreased soil loss (0.10 g/m2/s), fracture index, soil texture index (62.16), and crust index (1.18) significantly (P<0.01) in both incubation periods. Organic mulch, because of its higher O.M content, improved soil physical and mechanical properties and aggregate stability. This mulch played an important role by acting 1) as a physical barrier to protect aggregates against compression induced by flows, and 2) as a core for generating organomineral bonds. The increased Shs and PR as a result of cohesive and binding agents in the mulch composition, reduced the soil erosion compared to control. Due to the high percentage of silt in the studied soil, soil particles were weakly bound together with a low cohesion and strength. Therefore, adding the prepared mulches created physical and mechanical bonds between mulch and soil particles, enhanced the cohesion among individual particles, formed a coherent layer and increased soil Shs. MNF mulch, by creating chemical bridges between soil components, could facilitate soil aggregation. Compared to the soil incubated for 2 months, the effects of mulches on soil organic carbon were insignificantly reduced in the soil incubated for 4 months (2-month: 1.01%; 4-month: 0.97%). Soil loss rate, MWD, GMD and TS were significantly increased in the treatments with mulch However, this increase was insignificant for CI. The best results regarding reduction of soil erosion and improvement of soil physical and mechanical properties were obtained in the treatments with O mulch at all application levels and with MNF mulch in higher application levels. In mulch treatments in this study, the organic substances with soil modifying properties along with effective substances were used to improve soil stability, surface resistance and soil condition. Considering the lack of organic matter in Iran and warm climate of the study area, application of organic mulches is recommended to prevent soil erosion.

AUTHOR CONTRIBUTIONS

P. Gholamiderami performed the literature review, analyzed and interpreted the data. P. Lahooti provided the experimental design, performed the experiments and compiled the data. H. Darbam helped in the literature review and manuscript preparation.

ACKNOWLEDGMENTS

The authors acknowledge the collaboration of Yasuj Soil Technical and Mechanical Laboratory for providing support during measurement and sampling campaigns.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percent
°	Degree
°C	Centigrade
°C/min	Centigrade per minutes
AMSL	Above mean sea level
C	Carbon
CEC	Cations exchange capacity

CI	Crust index
cm	Centimeter
cm^3	Cubic centimeter
cmol/kg	Centimol per kilogram
CPM	Cellulose polymer mulch
ds/m	Decisiemens per meter
EC	Electrical conductivity
Eq.	Equation
et al.	"and others" in latin
FC	Field capacity
FI	Fracture index
Fig.	Figure
$g/m^2/s$	Gram per cubic meter per second
GMD	Geometric mean diameter
h	Hour
kg	Kilogram
kPa	kilopascal
kW	Kilowatt
M	MNF
m	Meters
m/s	Meter per second
mm	Millimeters
MWD	Mean weight diameter
O	Organic mulch
O.C	Soil organic carbon
pH	Potential of hydrogen
PR	Penetration resistance
rpm	Revolutions per minute
Shs	Shear strength
SiL	Silty loam
SOM	Soil organic matter
SPSS	Statistical package for social science
STI	Soil texture index
TS	Tensile strength
μs	Microsecond

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AUTHOR (S) BIOSKETCHES

Gholamiderami, P., B.Sc., Department of soil Engineering, faculty of agriculture, Sari Agricultural Sciences and Natural Resources University. Sari, Iran. Email: *parnd_gholami@yahoo.com*

Lahooti, P., M.Sc., Department of soil Engineering, faculty of agriculture, Sari Agricultural Sciences and Natural Resources University. Sari, Iran. Email: *parisa_lahooti69@yahoo.com*

Darbam, H., M.Sc., Department of soil genesis, Faculty of agriculture, Sari Agricultural Sciences and Natural Resources University. Sari, Iran. Email: *hamed_darbam71@yahoo.com*

HOW TO CITE THIS ARTICLE

Gholamiderami, P., Lahooti, P., Darbam, H., (2020). The effect of mulch on properties of erosion sensitive soil using a wind tunnel. Global J. Environ. Sci. Manage., 6(4): 537-552.

DOI: 10.22034/gjesm.2020.04.09

url: https://www.gjesm.net/article_39733.html