Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 16 | No. 4 | pp. 1313-1320 | 2017

Original Research Paper | Open Access

Using Bio-mulch for Dust Stabilization (Case Study: Semnan Province, Iran)

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 26-02-2016
Accepted: 16-04-2016

Key Words:
Dust storm
Bio-mulch
Dust stabilization
Wind erosion

ABSTRACT

The use of bio-mulches to stabilize dust has gained worldwide attention during the last five decades. We report herein on a study of the application of 20 new types of bio-mulches as stabilizing agents. To understand the effect of new bio-mulches on dust stabilization, several tests have been applied for strength, structural stability and wind erosion. Fourier Transforms Infrared and Scanning Electron Microscopy have been applied on untreated and treated soil samples. Bio-mulch modified mechanisms have been analysed. Wind erosion and aggregate stability test results clearly indicate that certain bio-mulch specimens were useful in controlling dust in relatively arid and semiarid areas. The Scanning Electron Microscopy images show that when bio-mulches were applied to sandy soil, some voids in the soil were filled, while other parts stayed on the surface of soil aggregates. The molecular structure of polyelectrolyte groups reacted chemically with positive ions of the clay grain and created physicochemical bonds between molecules and soil aggregates with ionic, hydrogen or Vander Waals bonds. Untreated samples had no bonds between molecules and soil aggregate, and the strength and erosion resistance were weak.

INTRODUCTION

Dust storms, one type of dust event, are in most cases the result of turbulent winds, including convective haboobs (Miller et al. 2008) that raise large quantities of dust from desert surfaces and reduce visibility to less than 1 km. This dust reaches concentrations in excess of 6000 $mg.m^{-3}$ in severe events (Song et al. 2007). The dust can be transported over thousands of kilometres and is deposited downwind by wet and dry processes; sometimes in appreciable quantities (O'Hara et al. 2006, Vukovic et al. 2014). Dust storms have a number of impacts upon the environment, including radioactive forcing and biogeochemical cycling that also affects human in a variety of ways, one of which is human health. Dust emissions from dried lake basins introduce fine particles, salts and chemicals (including herbicides) into the atmosphere, with a suite of health impacts, including respiratory and cardiovascular problems (Small et al. 2001, Goudie 2014, Sprigg et al. 2014). Dust storms lead to particulate levels that exceed the internationally recommended levels (Brunekreef & Forsberg 2005, Chu et al. 2008, Ozer et al. 2006) and transport allergens, including bacteria and fungi (Kellogg & Griffin 2006). The nature of future dust activity will depend on three main factors: anthropogenic modification of desert surfaces, natural climatic variability and changes in climate brought about by human activity, such as burning of fossil fuels and emission of greenhouse gases.

Application of stabilizing agents on soils has a long history. Cement mixed with soils was first used as a stabilizing agent at the beginning of the twentieth century. Since then, many other kinds of materials, such as lime (Bell 1996), fly ash (Dermatas & Meng 2003), organic polymers (Lahalih & Ahmed 1998), and their mixtures (Indraratna 1996), have been used as stabilizing agents. When stabilizing agents are added to soils, a series of reactions will take place, including pozzolanic reaction, cation exchange, flocculation, carbonation, crystallization, and dissociation (Gong 2005). These processes, strengthen the links between grains and fill the voids in soils, which improve the engineering properties of soils, such as strength and stiffness. The reactions occurring between stabilizing agents and soils are related to soil types.

Soil treated with a biopolymer solution show increased surface strength (maximum penetration force) and a higher biopolymer concentration, leading to a greater increase of the surface strength. There is a strong relationship between the dust resistance and the surface strength (maximum penetration force), indicating that penetrometer test method is a promising technique for characterizing the dust resistance of MTs (Chen et al. 2015).

Bio-mulch soil stabilizing agents applied in soil ecological stabilization have received recent attention (Barry et al. 1991, Nwankow 2001, Liu et al. 2009). The use of biopolymers has gained worldwide importance during the last five decades and they have shown great potential for use as soil additives to stabilize soil. The polymer has shown its ability to aggregate particles and form crusts: after a polymer solution has been sprayed over the sand surface, or wet sand has been mixed with the polymer, the particles show a strong tendency to aggregate. To improve the polymer anti-wind erosion ability, some natural polysaccharide materials such as xanthan gum and ethyl cellulose were introduced. The new soil stabilizers are environment-friendly products, acting as slow-release fertilizers, and are not toxic. Therefore, these new stabilizers are environment friendly and safe to use.

In the present research, 20 new types of bio-mulch soil stabilizers were tested. These bio-mulches have the following primary advantages. They (a) are comprised of water-soluble material that can be diluted to different concentrations; (b) are environment-friendly products with no additional pollution, and made of biodegradable water-soluble polymer; (c) can form an elastic and viscous crust on a soil surface under outdoor natural conditions; and (d) are easy to produce at relatively low cost.

Dust stabilizing agents were applied in soil plots to evaluate dust stabilization ability. To understand the effect of new bio-mulch on dust stabilization, untreated and treated soil specimens were tested for strength, structural stability and wind erosion. The modified stabilization mechanism for each agent was analysed.

This manuscript reports on this study that applied 20 types of bio-mulches as dust emission stabilizing agents. Specifically, this paper describes:

- The use of Xantan, ethyl cellulose and natural polymer as constituent materials in dust stabilization technology;
- The synthesized materials in tests of strength, stability and wind erosion;
- The performance characteristics (i.e. penetration test, wind erosion modulus and structural stability capacity) of the synthesized composites;
- The optimal material proportion for the synthesized composites.

MATERIALS AND METHODS

Sample preparation: Soil used for this study was acquired from western Tehran Province, Iran in 2013. The particle-size distribution of the soil is indicated in Fig. 1. Sample air-dried, sieved (<0.2 mm in diameter) soil was weighed (23 kg), and then placed into a tray with the dimensions presented in Fig. 2. Bio-mulches were first diluted with water (at the concentration of 1:3 V/V depending on the optimal concentration determined in the laboratory pretest). Then the soil surface in the tray was evenly sprayed by 2 L/m^2 of bio-mulch-water solution. After application of bio-mulches, the samples were dried under an outdoor natural condition for 48 h and 180 days, forming crusts on the

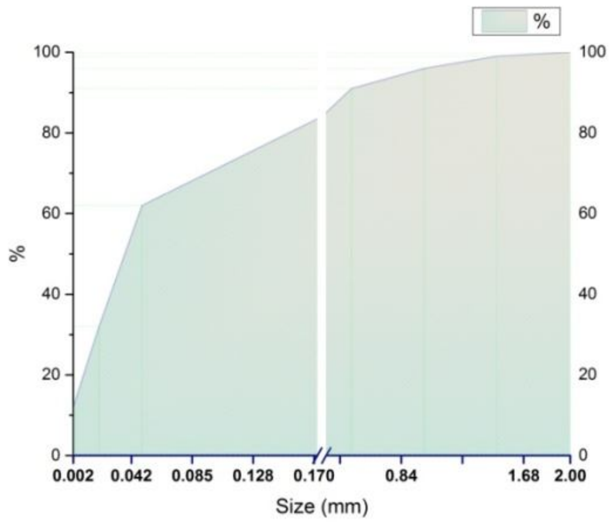


Fig. 1: Granulometric composition of the experimental soil (integral curve).

Fig. 2: Samples of soils placed into tray for test.

soil surface. Sprayed, pure water was also used in the experiment as a control. Parameters were measured after the crust surface formed. Three tests for crust strength, structural stability and wind erosion were performed to evaluate bio-mulch performance on dust stabilization.

Wind erosion test: Soil samples were placed in the wind tunnel for test as shown in Fig. 2. To compare the wind erodibility of the crusts formed by different bio-mulches, a wind tunnel was employed in an open circuit with a 928.3 cm long test section (800 × 800 mm) with a Plexiglass roof and door. Its working length was 928.3 cm and maximum wind speed reached 25.3 m/s. The wind velocities in the tunnel were measured by a Hot Wire Anemometer. The known dynamic pressure in the tunnel was used to calculate wind velocity. Amicro Dust Proaerosoil System (Model of HB3275-07) was used in this study.

Samples of about 23 kg of soil were filled in the tray (800 mm, 800 mm, and 20 mm) of the simulator. Twenty different bio-mulches (Namdar 2016) were sprayed on the surface of soil specimens uniformly. The spray content was 2 L/m^2. Treated specimens were placed in an outdoor natural condition for 180 days. After the surface crust formed, the wind erosion test was carried out. Tunnel wind speed was increased gradually from zero to maximum (about 25.3 m/s) over a 15 minute period each time. After the simulation of wind erosion, the crust thickness in ten surface locations over each specimen was measured with a caliper, and then the average values were used.

Penetration test: Crust formation is important to soil fixation. In this study, both crust thickness and strength of the specimens were measured. The sample penetration was measured at various times over a period of 180 days. Penetrometers were Mortar Penetration Resistance Apparatus (H-4137) and Concrete Pocket Penetrometer (H-4134). Ten bio-mulches were selected following the wind tunnel test. Water (without polymer) was used as a control. The penetration probe has a diameter of 1 and 1/3 inch with a flat end, which was gradually loaded until the soil crust was pierced. Five different surface locations on each specimen were penetrated for each test and their average values noted.

Soil structure test: The soil structure is an important parameter used to assess the effectiveness of dust stabilizing agents in the relatively arid and semiarid areas. Therefore, the following experiment was designed to evaluate the soil structure capacity when bio-mulch was applied to soil samples. The wet sieving apparatus 08.13 (Eijkelkamp Agrisearch Equipment) was used to determine the aggregate stability of a soil, which was the resistance of soil structure against mechanical or physicochemical destructive forces.

Fourier Transforms Infrared and Scanning Electron Microscopy: Each 10-15 g (soil with bio-mulch) sample was selected. Approximately 5 g of each surface bio-mulch was extracted and passed through a 0.05 mm mesh sieve. The remainder was stored in a closed glass vial pending further examination.

RESULTS AND DISCUSSIONS

Wind erosion test: The property parameters of soil used in this study are presented in Table 4. The dominant component of the soil particle size was between 0.02 and 0.250 mm. Wind erosion simulations were made to test untreated and treated specimens. Evaluation of the test results is presented in Fig. 3. As observed, compared with the untreated specimen, the treated specimens have higher anti-wind erosion ability. The surface crust in treated specimens can prevent surface erosion and dust formation. The crust thickness of specimens in S_3 to S_{14} was between, approximately 2.15 and 2.85 cm (Fig. 4). Treated specimens have good wind erosion resistance due to the crust in the surface layer. The data reveal significant differences (P<0.01) among S_1, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12}, S_{13}, S_{14}, S_{15}, S_{19} and S_2, S_{11}, S_{16}, S_{17}, S_{18} specimens. S_1,S_2, S_{11}, S_{13}, S_{15} S_{16}, S_{17}, S_{18} and S_{19} specimens were destroyed in 25.3 m/s wind velocity. Fig. 5 shows destroyed and resisted specimens. The test results clearly indicate that S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12} and S_{14} would likely be considered to control dust in the relatively arid and semiarid areas represented by these soil samples. Therefore S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12} and S_{14} specimens were selected for aggregate stability, FTIR and SEM tests for choosing the best bio mulch.

Penetration test: The resistance of the aforementioned probe at different penetration depths was taken as a reference value of the penetration of each specimen. The penetration test variation was taken in a vertical direction, where the surface

Table 1: Property parameters of soil used in this study.

Depth (cm)	Silt (%)	Clay (%)	Sand (%)	Texture	O.C* (%)	CEC** Cmol(+) kg^{-1}	EC_e*** dS m^{-1}	pH	Moist colour
0-30	20	12	68	Sandy Loam	0.38	10.40	2.18	7.37	10YR4/3

*Organic Carbon **Cation Exchange Capacity ***Electrical Conductivity

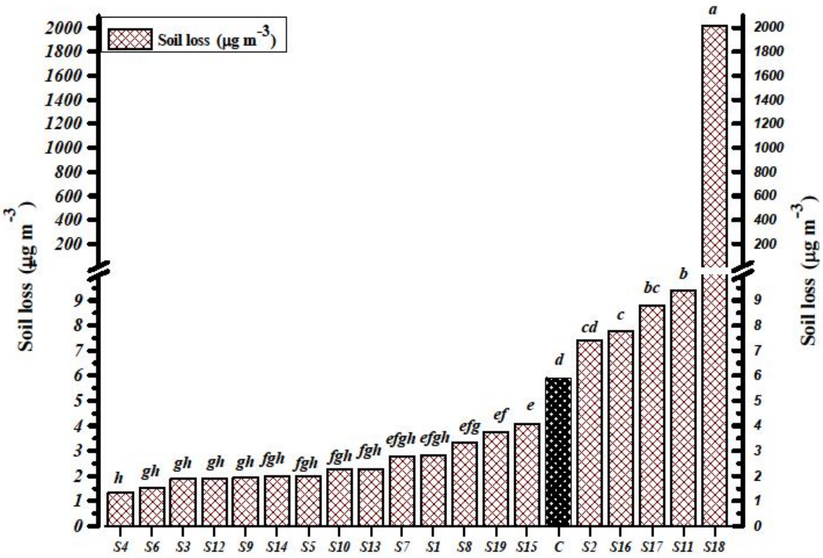


Fig. 3: Real particulate concentration of bio-mulches in µg/m^3 (Tukey HSD^{a,b} analysis with subset for alpha = 0.05 and 0.01 for soil loss (mg.m^{-3}) *Variables with the same letter in the top of each column are not statistically different at the 0.05 and 0.01 level*).

Fig. 4: Crust thickness of specimen (S4).

crust thickness and specimen strength were determined. Data indicate significant differences (P<0.01) between S_1, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12}, S_{13} S_{14}, S_{15} and the untreated sample. All S_1, S_4, S_5, S_6, S_7, S_8, S_{10}, S_{13} and S_{15} specimens were significant differences (P<0.05) from the S_3, S_9, S_{12} and S_{14} specimens (Fig. 6). It is clear from the untreated and treated specimens that the presence of bio mulch affects penetration in the surface layer. Presence of surface crust will enhance the bonding force or cohesion between the particles and increase soil stability. The higher soil surface resistance to erosion was mainly observed when the time of treatment is longer than 48 h. The specimens treated such as S_3, S_4, S_5, S_8, S_9, S_{12} have crust thicknesses of approximately 2.15-2.85 cm. When bio-mulch was applied to the soil surface, a portion filled the voids in the soil, while the other part remained on the surface of the soil particles. The anionic polyelectrolyte of polymers enwraps the particles' surfaces to create bonds that interlink and then form an elastic and viscous crust on the soil surface. Normally, the formation of crust requires a few days, and the thickness and strength of the crust might be affected by time.

Aggregate stability test: The results of aggregate stability specimen tests are presented in Fig. 7. Significant differences (P<0.05) between S_4, S_5, S_6, S_7, S_8, S_9, S_{10} and control are observed. These results show that the application of bio-mulch clearly improved the aggregate stability of soil. Hence, from these composites, S_4, S_5, S_6, S_7, S_8, S_9 and S_{10} specimens were selected for FTIR and SEM tests. Following these tests, three bio-mulches were selected for the field tests.

Fourier transform infrared: The results of FTIR on S_4, S_8 samples in the 180-day drying period are shown in Fig 8. Fig. 8 is a typical soil subtraction spectrum and exhibits absorption bands at 3411.45, 1027.74, 521.32 and 1430 cm^{-1} after 2 and 180 days. Differences between spectra were not insignificant (P>0.05). Hence, these results show that during the 180 day period not all absorption bands changed completely.

Mechanisms of stabilization: Normally, soil stabilization mechanisms of bio-mulch soil stabilizer include filling, chemical reaction and enwrapping (Barry et al. 1991, Nwankow 2001). As mentioned, when the bio-mulches were applied to sandy soil, part filled up the voids of soil (Fig. 9) and the remainder stayed on the soil aggregate surface. The

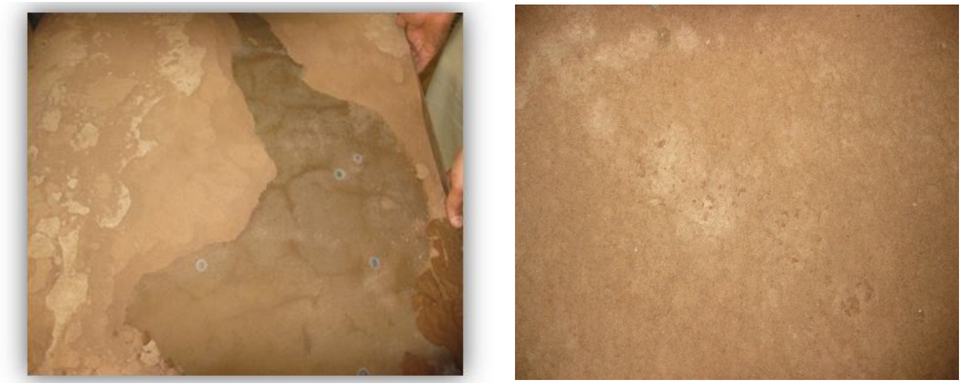


Fig. 5: Soil trays Left (destroyed) and Right (resisted erosion) specimens after the 15 min wind tunnel test in 25.3 m/s wind velocity.

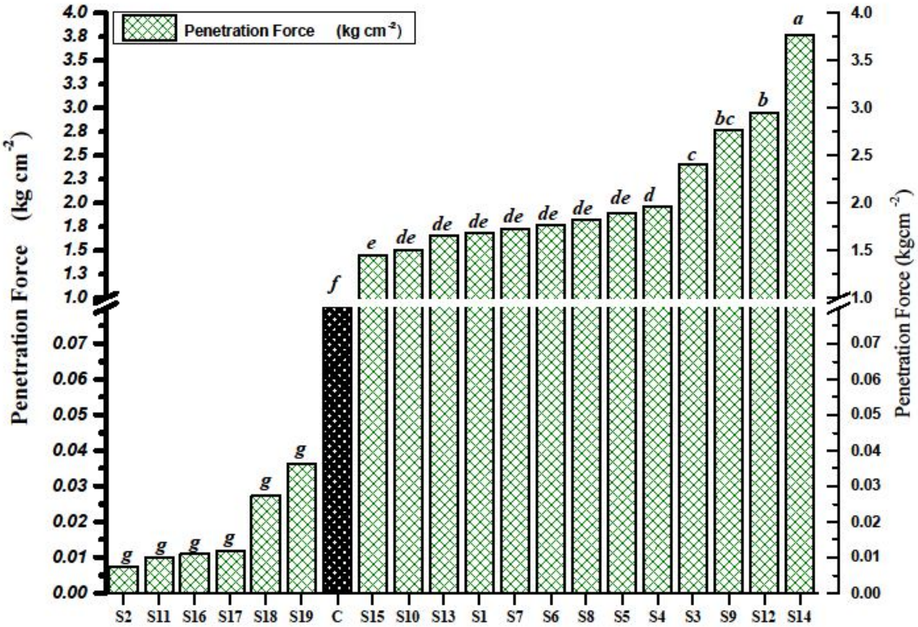


Fig. 6: Compressive, structural strength of crust, by bio-mulch solution (kg/in^2), after 48 h (Tukey HSDa,b analysis with subset for alpha = 0.05 and 0.01, *Variables with the same letter in the top of each column are not statistically different at the 0.05 and 0.01 level*).

physicochemical bonds are created between polymer and the positive ions of clay through ionic, hydrogen or Vander Waals bonds, when the polymer is applied to soil. The soils vary in characteristics and polymer solution dynamics. Through these bonds, long chain macromolecules of polymers enwrap the soil's aggregate surface and create an elastic and viscose membrane structure. Fig. 9 shows the smooth exterior surface morphology that was formed by polymer molecules penetrating into the inner aggregates and bonding with them (Fig. 9B). Untreated samples failed to develop bonds between molecules and soil aggregate (Fig. 9A), resulting in weak strength and erosion resistances. Through bonding, long-chain macromolecules of polymers enwrap the aggregate's surface and interlink to form an elastic and viscous membrane structure. Thus, the strength, water stability and erosion resistance are improved.

The physicochemical reactions between soil stabilizer and soil usually require a few days. The strength increases quickly in the first 48-hours, and then slows to a constant value. Also, the filling of voids and the formation of physicochemical bonds in the reactions of stabilized soil, lead to increase in bonding and interlocking forces between soil particles. As a result, penetration resistance and cohesion of the sandy soil is improved after treatment. In this study, the

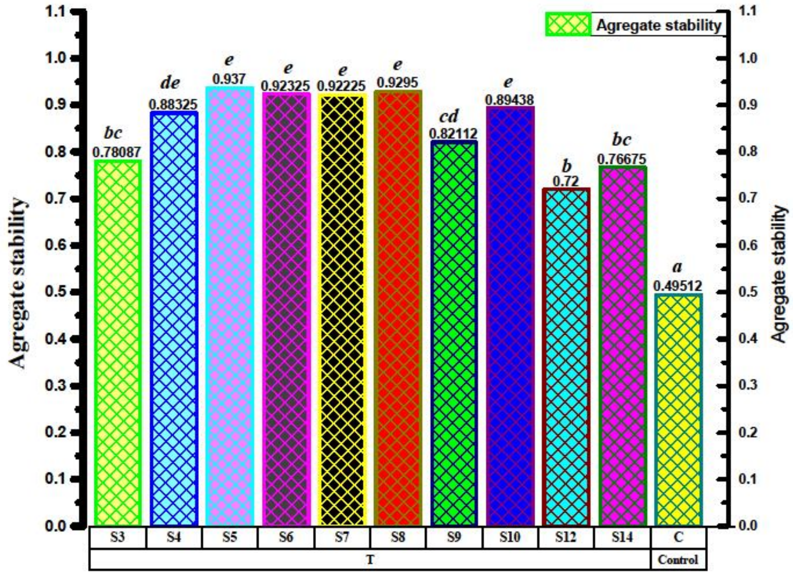


Fig. 7: Aggregate stability of specimens.

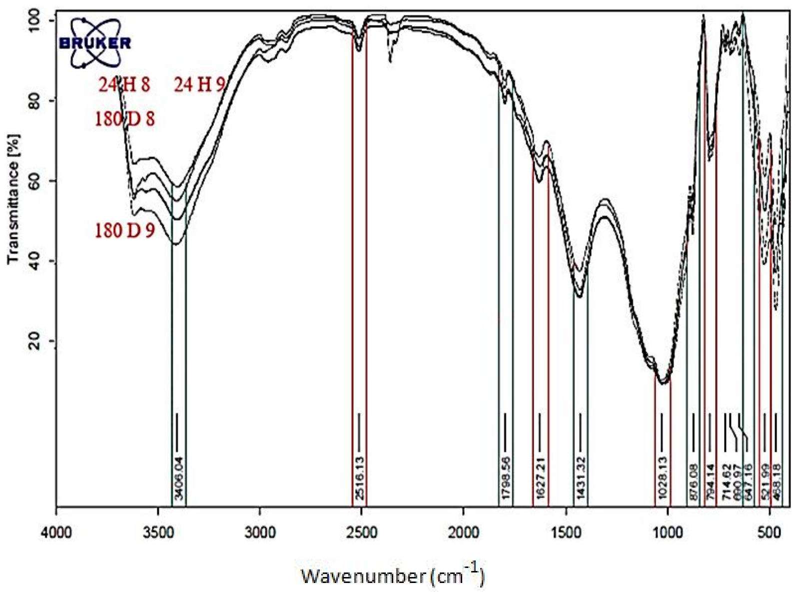
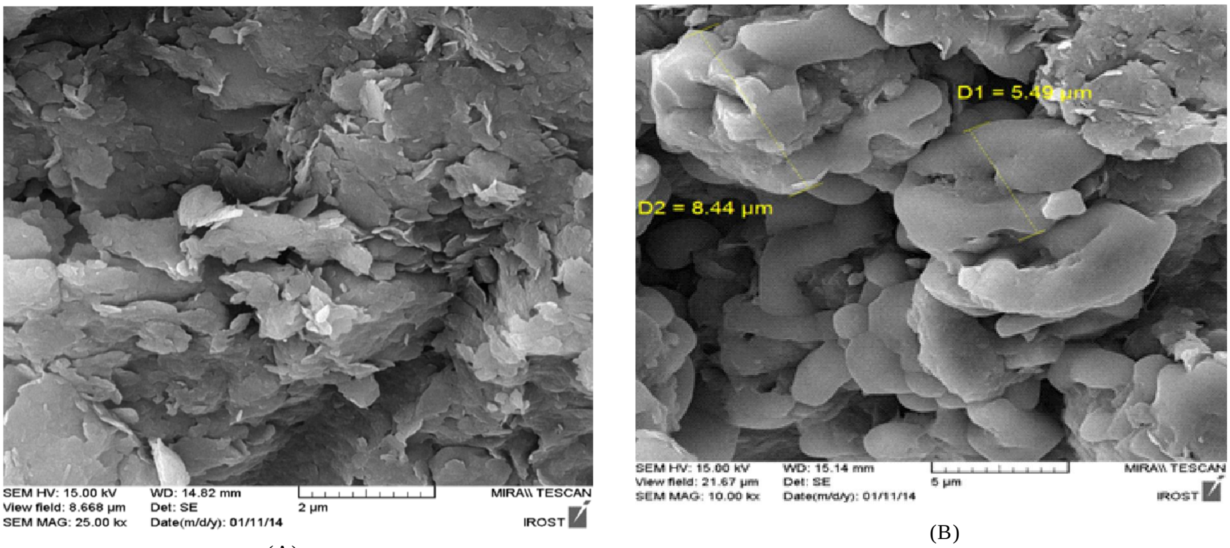


Fig. 8: FTIR spectra of bio-mulch (S_4, S_8).

molecules of bio-mulch could have already been enough to fill most of the soil voids, and the groups-CH_2OH- Xantan (Fig. 10) in molecular form, might have fully reacted with the clay particle. When bio-mulch is applied to the soil, the formation of physicochemical bonds and membrane structure lead to an increase in water stability and erosion resistance. This helps the formation of a more complete membrane structure on soil aggregate surfaces and then increases the particle cohesion. Biopolymer forms coating on the MT particle surface, generates a cross-linking network between MT particles, and leads to a denser structure of MTs, thus increasing the surface strength, enhancing the moisture retention capacity, and improving the dust resistance (Chen et al. 2015).

CONCLUSIONS

Compared with the untreated specimen, treated specimens have higher anti-wind erosion ability. Surface crust in treated



(A) (B)

Fig. 9: SEM image of soil (B) void filled by bio-mulch with 5μ time magnification and (A) without bio-mulch with 2μ time magnification.

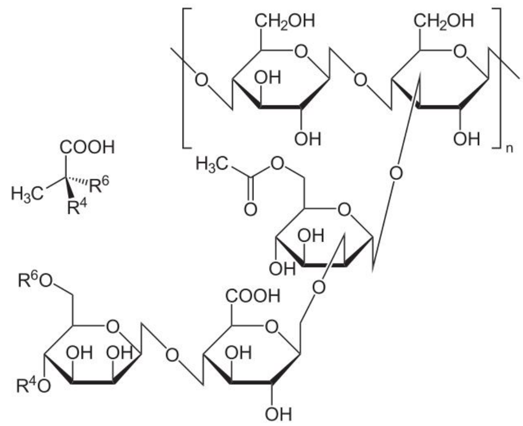


Fig. 10: Structure of Xanthan polymer.

specimens can prevent erosion of the surface and prevent dust emission. The crust thickness of specimens in S_3 to S_{14} was approximately between 2.15 and 2.85 cm, which improved treated specimen wind erosion resistance and aggregate stability within the surface layer. Results show that S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12},S_{14} have improved the anti-wind erosion ability more than S_2, S_{11}, S_{15}, S_{16}, S_{17}, S_{18}, S_{19} specimens. Of this last group, all specimens were destroyed in 25 m/s wind velocity. After aggregate stability test S_4, S_5, S_6, S_7, S_8, S_9 and S_{10} specimens were selected for FTIR and SEM tests. Following these three tests, three bio-mulches were selected for field tests. The SEM analyses indicated that the polyelectrolyte groups in their molecular structure had a chemical reaction with positive ions of clay grains and created physicochemical bonds between molecules and soil aggregates with ionic, hydrogen or Vander Waals bonds. Untreated samples did not develop bonds between molecules and soil aggregate. Through bonding, long-chain macromolecules of polymers enwrap the aggregate's surface and interlink to form an elastic and viscous membrane structure. Strength, water stability and erosion resistance of the soil surfaces were improved. When bio-mulch is applied to the soil, the formation of physicochemical bonds and membrane structure lead to increased water stability and erosion resistance.

ACKNOWLEDGMENTS

This work was financially supported by Tarbiat Modares University (TMU). The authors express their deepest appreciation to A. Shojaodini and S. Rangrizi for the technical support and to the Iranian Research Organization for Science and Technology (IROST) for guidance and support.

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