The Impacts of Nanoclay on Sandy Soil Stability and Atmospheric Dust Control

Marjan PADIDAR [1(✉)]
Ahmad JALALIAN [2]
Kamran ASGARI [1]
Majid ABDOUSS [3]
Payam NAJAFI [4]
Naser HONARJOO [2]
Jaber FALLAHZADE [1]

Summary

Wind erosion and dust storms are main issues in arid and semi-arid regions. Application of soil stabilizer on unstable land might be an effective and sustainable strategy in arid and semi-arid countries to minimized harmful effects on environment and human health. The aim of this study was to assess the effect of using nanoclay for increasing soil stability, as a result of increasing in size of soil aggregation, and improving soil water holding capacity, as well as improving soil structure in sandy soil. An experiment was conducted with two treatments (0 and 3000 mg/l nanoclay were uniformly spread on the soil surface) in four replications on sandy soil, in Khara desert, nearly 100 km east of Isfahan, Iran. The annual rainfall is about 68/55 mm, mean annual ET_0 is 2800 mm/year, and the elevation is 1450 m above sea level. Amount of soil erosion was measured with different wind velocity (31.0, 55.2 and 67.3 km h^{-1}). An aggregation size and water retention of collected soil samples were measured by sieves and pressure plate, respectively. The results showed that the amount of soil erosion in nanoclay-treated soils was significantly different ($P>0.05$) in comparison with water-treated (control) soils. The volumetric water content at 100 KPa increased in nanoclay-treated soils compared to control treatment. Results also showed that the proportion of 0.25-2 mm aggregate (macro-aggregate) significantly increased in nanoclay-treated soils. Based on aforementioned results, it can be concluded that application of nanoclay on soil surface is able to fix the sand and it has ability to cement the particles to each other, increase aggregation and reduce wind erosion. The results suggested that more attention should be directed towards using nanoclay on soil surface of unstable soil areas. That coild be an option for control of the atmospheric dust.

Key words

wind erosion, wind tunnel, dust storms, nanoclay

[1] Young Researchers and Elite Club, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
✉ e-mail: M25padidar@gmail.com
[2] Department of Soil Science, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[3] Department of Chemistry, Amirkabir University of Technology, Tehran, Iran
[4] Department of Water Science, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

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Introduction

Dust storm is a common meteorological phenomenon in arid and semi-arid regions. Environmental impacts of dust storm in the air have been increasingly recognized by researchers (Mbuh, 2011). Wind erosion as the ultimate cause of the dust storm, is one of the critical environmental and agricultural problems that has a serious impact on air quality, agricultural lands, water reservoirs, irrigation canals, air pollution and aerosol transmission (Azimzadeh et al., 2008, Soleimani and Modallaldoust, 2008, Menut, 2013). The major factors that influence desertification are climate, wind erosion, low level of land management, vegetation degradation, and the salinization of soil and water resources (Farajzadeh and NikEgbal, 2007). Over the last decade, various changes in land use increased frequency and intensity of dust storms in arid and semi-arid regions (Gerivani et al., 2011). Increasing in the number of dusty days and the level of air dust has serious effects on the human health and plays an important role in the climate system (Boloorani et al., 2014; Khodabandehlooa et al., 2013). It is estimated that 26.4 and 35.4 million hectares of land in Iran are under the influence of water and wind erosion, respectively (Lal, 1999). Several methods were used for stabilizing Aeolian soils (Armbrust et al., 1964; Akbarian, 2010; Vaezi, 2010; Movahedan, 2011). Nanotechnology, in one aspect, is a science to design, synthesis, characterization and application of material on nanometer scale (Ramsden, 2011). This science could have several applications in soil science (Lal, 2007). Among the nan-particulates, nanoclay is a viable commercial material that was one quarter in 2005 of total nanocomposite consumed (Uddin, 2008). One of the most important aspects of nanoclay is their ability to cement the particles to each other, and therefore leads to more stability of aggregates. Nanoclay is able to fixate the sand and it has ability to stabilize the soil structure and decrease soil erosion. Using nanoclay on the soil surface could enhance the capability of avoiding the wind erosion (Padidar et al., 2014). The results of an investigation that applied nanoclay to sandy soils in Egypt showed that nanoclay could decrease wind erosion (Olesen, 2010). Montmorillonite nanoclays are hydrophilic and have a platy structure with a unit thickness of one nanometer or less (Armstrong and Fortune, 2007). The objective of this study was to assess the effect of using nanoclay for increasing soil stability, as a result of increasing in size of soil aggregation, and improve soil water holding capacity as well as improve soil structure in sandy soil.

Materials and methods

The study area was located on the Khara desert in Central of Iran (located between 32° 00' N and 32° 23'N and 52°40'E and 52° 47'E, at 1450 m above sea level) (Figure 1). Khara Desert is situated on the semi-arid plateau of central Iran, with dry and hot summers and mild winters. Mean annual rainfall is approximately 68.55 mm; mean wind speed is approximately 12.4 m s^{-1} (44.64 km h^{-1}) mean annual ET_0 is 2800 mm/year, and mean monthly temperature range from 5.6 to 42°C. The soil was an Entisols (NRCS 2014) with 96% sand, 3% silt and 1% clay. The temperature and moisture regimes of the soil are Thermic and Aridic, respectively. The soils of this area are structurally unstable and sandy texture makes these soils highly erodible for most seasons. In order to mitigate soil erosion under wind conditions, the Nanoclay solution (Cloisite Na+, BYK Company) was sprayed onto the soil surface using motorized sprayer. Soil surface was treated uniformly with spray of 500 ml of solution to moisten 5 cm depth of the soil. Wind Erosion Meter (Figure 2) was used to make wind with specific speeds (31.0, 55.2 and 67.3 km h^{-1}) in specific time (5.0 min). It is typical portable wind tunnel that can be used in laboratory and desert. This device is consisted of three main parts including: wind generator fan, metal casing of wind tunnel and plastic chamber of sediment storage. Threshold velocity (31 km h^{-1}) is defined as the minimum velocity that causes soil particles to move.

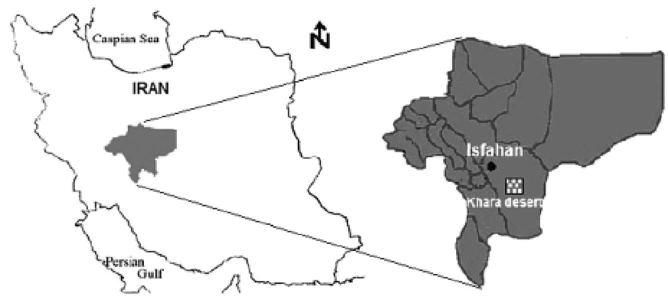

Figure 1. Location of the study area in central Iran

The size distribution of soil aggregates was measured by dry sieving through a series of sieves (2, 1, 0.5, 0.25 and 0.05 mm). For this reason, 50 g of air-dried soil sample was spread uniformly on the top of a 2 mm sieve. The sample was shacked using a portable flat-sieve shaker for 1 min. The material that passed through each sieve was separately weighed and combined into macro-aggregate (0.25–2 mm) and micro-aggregate (0.05–0.25 mm) groups. For each treatment, three replicates of soil samples were used. Soil samples in the small core samplers (5*5 cm) were taken to measure the water retention (at 100 kPa) and were imposed using a pressure plate apparatus (Dane and Hopmans, 2007).

Figure. 2. Wind erosion meter

Table 1. Effect of nanoclay on the soil erodibility (g eroded soil) at three wind speeds in field experiment

Wind speed (km h^{-1})	Nanoclay concentration (mg/l water) in 500 ml water		Ratio (Control/Nanoclay)
	0	3000	
31.0	0.9675 a	0.025 b	38.70
55.2	21.285 a	0.055 b	387.0
67.3	475.304 a	1.00 b	475.304

In each row, unsimilar letters indicate significant difference ($p < 0.05$). Each value represents means ± S.E. (n = 4).

The data were statistically analyzed using the package STATISTICA 10 (StatSoft 2011). Statistical significance was detected using the independent samples *t* test and analysis of variance at α = 0.05. Effects of nanoclay on soil erodibility, aggregation and water retention were determined by one-way Analysis of Variance (ANOVA).

Results and discussion

The effect of nanoclay on soil erodibility at three wind speed (31.0, 55.2 and 67.3 km h^{-1} for 5 min) is presented in Table 1. The results showed that amount of eroded soil increased with increased wind speed. However, amount of eroded soil in treated surface with nanoclay was significantly lower than control treatment. The rate of soil erosion on the surface wetted by distilled water in 31, 55.2 and 67.3 km h^{-1} wind speed were 38.7, 387 and 475 times more than the surface wetted by nanoclay solution, respectively. The results clearly showed that use of nanoclay on the soil surface can enhance the capability of soil against the wind erosion (Table 1). Majdi et al. (2006) reported that clay mulch was resistant to wind erosion, but erosion took place when the clay mulch was exposed by sandblast.

The effect of nanoclay on the proportion of aggregate size is represented in Figures 3 and 4. The results revealed that the proportion of 0.05-0.25 mm fraction (micro-aggregate size classes) significantly decreased (from 1.6 to 0.16%) with increased nanoclay concentration (Figure 3) whereas, the proportion of 0.25-2 mm fraction (macro-aggregate size classes) increased (from 48 to 49 %) with increased nanoclay concentration (Figure 4). Therefore, nanoclay can generate aggregates and it has a positive effect on the structural stability of the sandy soil and the process of binding the soil particle. The using of nanoclay also increased soil water retention significantly compared to control sample at 100 KPa (Figure 5). Olesen (2010) also showed that nanoclay is able to increase the amount of soil water in desert, which gives the soil more resistance to erosion (Attom, 2012).

In this paper, physical properties of the soil under Nanoclay treatments were studied. However, the effect of nanoclay on chemical and microbiological properties of the soil should be considered before using the nanoclay in wide area.

Conclusions

Wind erosion and fine dust emissions are influenced by soil moisture and soil aggregates mainly in sandy soils. Based on aforementioned results, nanoclay treatment reduces at least 95% of erosion in comparison to water treatment. Physical properties of soil such as a proportion size and capability of water holding are weak in sandy soils. Using nanoclay in sandy soil clearly showed that soil structure improves by increased soil aggregate size and balanced proportion of pores size distributions. Using nanoclay

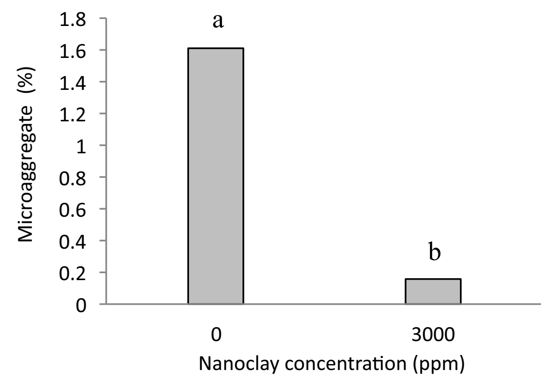

Figure 3. Effect of nanoclay on proportion of micro-aggregate size classes (0.05—0.25 mm); Unsimilar letters indicate significant difference ($p < 0.05$).

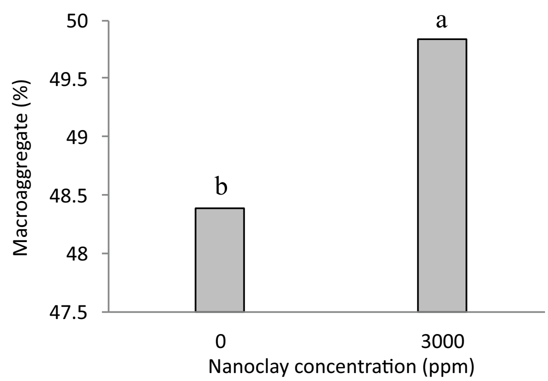

Figure 4. Effect of nanoclay on proportion of macro-aggregate size classes (0.25—2.0 mm); Unsimilar letters indicate significant difference ($p < 0.05$).

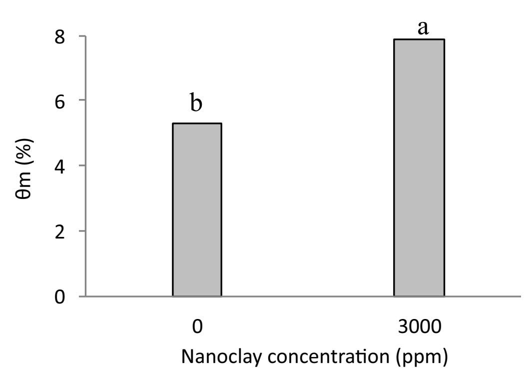

Figure 5. Effect of nanoclay on soil water retention at 100kPa; Unsimilar letters indicate significant difference ($p < 0.05$).

also increases soil water holding as a result of improvement in soil structure and soil pores. These changes increase ability of wind erosion control by forming stable and coarse aggregates on the soil surface. The results suggest that more attention should be directed toward the roll of nanoclay in stabilization of the soil in unstructured lands mainly in arid and semi-arid regions. It should be mentioned that results of the research of nanoclay influence in this paper refer only to the physical properties of the soil. There is a need to investigate the effect of nanoclay on the chemical properties of the soil and microbiological activity, before the use of nanoclay in practice could be recommended.

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