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Interaction of petroleum mulching, vegetation restoration and dust fallout on the conditions of sand dunes in southwest of Iran

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ABSTRACT

In the past half-century, petroleum mulching-biological fixation (PM-BF) practices have been employed to stabilize sand dunes in Iran. However, the effects of PM-BF practices on the attributes of sand dunes and the dispersion of heavy metals of mulch have been poorly understood. To this end, three regions treated with PM-BF for 5, 20, and 40 years and a control region with no PM-BF were studied. Samples of soil properties were taken at the depths of 0–10 cm and 10–50 cm, with three replications, in Khuzestan Province. The results showed that PM-BF practices promoted the restoration of vegetation cover in the sand dunes. In addition, these practices increased the deposition of dust particles, gradually increasing the magnitudes of palygorskite and smectite clays over time. The interactions between dust deposition and PM-BF practices significantly altered the chemical and physical properties of the dunes. PM-BF practices increased soil organic matter (184–287%), cation exchangeable capacity (142–209%), electrical conductivity (144–493%), clay content (134–196%), and penetration resistance (107–170%) compared to the region with no PM-BF practices. Furthermore, petroleum mulching significantly increased the amount of Ni (1.19%), Cd (1.55%), Pb (1.08%), Cu (1.34%), Zn (1.38%), Mn (1.66%), and Fe (1.15%). However, in the long term, these elements will probably leach linearly as a consequence of an increase in organic matter and soil salinity in the light texture of sand dunes.

1. Introduction

Sand dunes (Ahmadi et al., 2002) and dust storms (Zarasvandi et al., 2011) are two of the most serious problems of arid regions in Iran because they cause damage to cities, villages, communication lines, installations, and various factories each year. According to current estimates, wind erosion has affected more than 400,000 ha of land area in Khuzestan province, more than 270,000 ha of which are sand dunes. Therefore, in the past half-century, approximately 70,000 ha of these lands have been stabilized with PM-BF practices (Khalilimoghadam et al., 2015).

Various types of mulch are widely used around the world for sand dune stabilization. Although the biological establishment of sand dunes is one of the fixation methods for stabilization, in many cases, the establishment of plant species requires the initial stabilization of sand dunes (Rezaie, 2009). Thus far mulches such as heavy petroleum products, bitumen emulsion, sodium chloride solution, sodium or potassium carbonates, fiber, stone, glass wool, thin layers of plastic, polyethylene, and cellophane have been utilized to stabilize sand dunes (Homauoni and Yasrobi, 2011). Mulches are compounds that can increase soil strength against wind shear forces and prevent the separation of particles of sand dunes (Wuddivira et al., 2013). The mulch compounds can increase sand cohesion and inter-particle friction in sand dunes. Due to their cohesion properties, clay, polymer, petroleum, and organic matter mulches cause the particles of sand dunes to stick together (Khalilimoghadam et al., 2015). Moreover, owing to their lower ionic double layers, salts cause the flocculation of particles of sand dunes. Li et al. (2014) showed that soils with higher salinity have lower wind erodibility than non-saline soils.

The main base of the petroleum mulch is a wide range of compounds of heavy petroleum hydrocarbons that are divided into different parts, which have a different chemical composition that includes saturated naphthene, polar aromatics, and asphaltenes (Akbarnia, 2009). Crude oil is a colloidal mixture in which metals are present in organic and inorganic forms (Wang et al., 2010). The chemical decomposition of petroleum compounds with different viscosities and concentrations of asphaltenes showed that higher oil residuals result in higher heavy metals. When soil and live tissues contaminated with the crude oil were analyzed, Ni, V, Pb, Cu, and Cd were extracted (Duyck, 2009). Li et al. (2014) concluded that petroleum mulching increases soil quality due to the increase in the nutrient matter (N, P, K, and micronutrients). They demonstrated that petroleum mulch creates pores in the soil, thus

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enhancing plant growth. Akbarnia et al. (2005) concluded that the use of petroleum mulch in some regions of Khuzestan increases sand dune stabilization as well as vegetation. According to their results, the decomposition of molecules of petroleum hydrocarbon in the soil causes an increase in the amount of organic matter.

In addition to the phenomenon of sand dunes, the phenomenon of dust storm has been observed and exacerbated in recent decades due to climate change and human factors such as the construction of large dams, intensive grazing in pastures, lack of crop rotation, monoculture, drying wetlands, and regional conflicts in the Middle East region. Accordingly, Khuzestan province is affected by dust storms arising from internal and external sources such as Iraq, Syria, and Saudi Arabia. The effects of dust storms may continue at a distance of 4000 km from the main source and cause biotic effects and great damages in the fields of agriculture, industry, transport, and telecommunication systems (Zarasvandi et al., 2011).

The results obtained from many samples of dust storms in Khuzestan province confirm that the constituent minerals of the samples investigated are generally in the three phases of main minerals, including carbonate (mainly calcite), silicate (mainly quartz), and phyllosilicate (mainly kaolinite). The clay minerals, as the secondary mineral phase, play a role in the absorbance of some heavy metals (Zarasvandi et al., 2011). These findings indicate that in the majority of samples, the frequency of calcite and quartz as the main products in the destructive sediment environments demonstrates rather a sedimentary source for dust storm particles in Khuzestan (Zarasvandi et al., 2011).

Hojati et al. (2012) stated that the majority of minerals in the dust storm striking Jandagh to Koohrang contain more quartz and calcite and less dolomite, gypsum, and halite. Mahmoudi and Khademi (2014) demonstrated that the clay mineralogy compound of dust storm particles contains palygorskite, smectite, chlorite, illite, kaolinite, feldspars, and quartz. Other researchers reported that the constituent minerals of dust storm particles are quartz (Cattle et al., 2002; Hojati et al., 2012), palygorskite and feldspars (Fiol et al., 2005), micas (Küffmann, 2003), and magnetite (Reynolds et al., 2006). Dust storms in lowlands result from multiple mechanisms of natural and anthropogenic disturbance and can be transported far from the source (Steenburgh et al., 2012; Vandenberghe, 2013; Inmaculada et al., 2014). After their deposition, dust storms cause serious effects on ecosystem, including changes in the hydrological cycle (Painter et al., 2007, 2010; Jeffrey et al., 2015), the chemical characteristics of surface water (Brahney et al., 2014; Moser et al., 2010; Psenner, 1999), and soil formation processes (Dahms, 1993; Lawrence et al., 2011).

Although petroleum mulching-biological fixation (PM-BF) practices aimed at stabilizing sand dunes have a history of more than a hundred years, there are few research reports in this regard, and what is on hand is more indicative of the utility of this type of mulch for temporary mechanical stabilization of sand. However, the long-term effects of PM-BF practices and their interactions with dust storms on different characteristics of sand dunes have not been investigated yet. Therefore, this research was carried out in stabilized regions of sand dunes in Khuzestan province with a history of 2 to 50 years. The aim was to address the long-term effects of PM-BF practices on the physical and chemical properties of sand dunes and heavy metals and the trend of changes in clay minerals.

1.1. Study area (Physiographic conditions and history)

In this region, there are three morphologies of sand dunes. The dominant morphology is the seif dunes created due to the presence of western and southeastern winds with acute angles. In addition, the morphology of transverse ridges is obseved in this region, which has been formed owing to the movement of barchans under the influence of the collision of two dominant winds in the region with obtuse angles and their connection with each other. Single barchans are also scattered throughout the region (Iranian Institute of Forest and Rangelands Research, 2005). Fig. 1 shows the frequency distribution of the direction of the winds in the region. Based on morphoscopy studies, the mode diameter of sand dunes in this region is approximately 166–214 μm. These almost equal diameters indicate the existence of a concentric source for the sand dunes in this region. The most frequent diameter of the sand dune particles is 180 μm, and the displacement distance of these particles is estimated to be approximately 20–25 km, indicating the nearness of the source of the sand dunes. The sorting of the samples is very good (0.1–3) and the skewness of their particles is toward fine grain. The sand dunes have not been moved from a far distance and are mainly originated to discontinuous sandstones in the west and northwest regions. Calcareous materials constitute more than 60% of these sands whose compounds are almost the same as those of Aghajari formation sand stones (Iranian Institute of Forest and Rangelands Research, 2005).

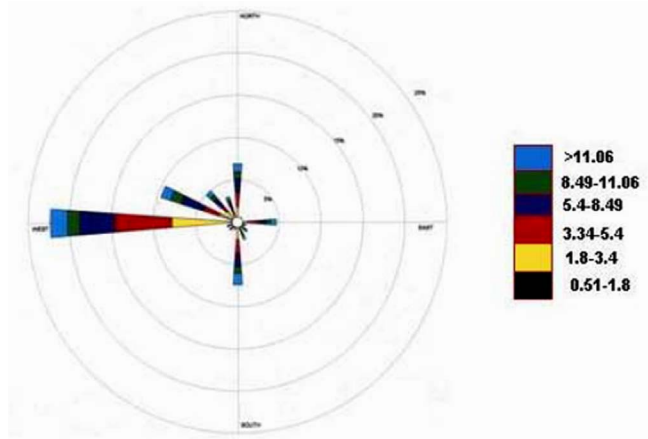

Fig. 1. The frequency distribution of the direction of the winds in a 30 year time period.

2. Materials and methods

2.1. Experimental area

The present study was conducted in the stabilized sand dunes of Khuzestan province in the southwest of Iran (Fig. 2). The average annual air temperature in this region is 24.5 °C. In addition, the mean monthly maximum air temperature of 45.9 °C is observed in July and the average annual minimum air temperature of 5.98 °C is observed in January. The average maximum temperature of the warmest month (July) is 50 °C and the mean minimum temperature of the coldest months (January and February) is 3.2 °C. The average annual rainfall of 261.7 mm and the mean monthly maximum rainfall are reported in January and December. In this station, there are 6.1 days with less than one millimeter of rainfall in a single year, 25.6 days with more than one millimeter of rainfall, and 7.9 days with more than 10 mm of rainfall.

In Khuzestan province, for sand dune stabilization, petroleum mulch of 1 mm thickness could be sprayed on sand dunes, a process known as petroleum mulching (PM). The mulches consumed are mostly petroleum-based and are produced by Abadan Oil Refineries. Petroleum mulch is a colloidal mixture of a wide range of heavy hydrocarbon compounds which are classified into the following four fractions: saturates, naphthene, polar aromatics, and asphaltenes (Akbarnia, 2009). After that tree seedlings such as *Prosopis cineraira* and *Tamarix hispida* are planted. Due to its cohesive property, petroleum mulch prevents the movement of sand particles and helps the tree seedling to grow by the full establishment. The stabilized region was excluded for several years and the entrance of livestock was prevented for many years. The practice of tree planting and exclosure after mulching is called biological fixation (BF). A significant part of the mulch sprayed was decomposed by the biological activity of soil organisms and chemical