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Combating wind erosion of sandy soils and crop damage in the coastal deserts: Wind tunnel experiments

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ABSTRACT

In the western Negev desert of Israel frequent sandstorms cause heavy damage to young lettuce, carrot, peanut and potato plants during the planting season. The damage of plants is based mainly on the mechanical impact of saltating sand particles, which causes irreversible injuries to the plant leaves. Current agro-technique measures taken to prevent wind damage to crop in Israel are based on high frequency irrigation. Although the high-frequency irrigation helps bind soil particles together by forming a soil crust, it is associated with the large waste of water, which is not practical under the arid conditions.

Application of polyacrylamide (PAM) as a chemical stabilizer has proved to be effective for prevention of soil erosion, saving irrigation water and a stable growth of plants in the early stages. Although the technique of PAM application is not yet used commercially in Israel, the preliminary studies suggested that it might have the potential to reduce the damage to the plant leaves by sandstorms, providing both environmental and agricultural benefits. In this study the effectiveness of PAM for preventing sandstorms in the western Negev was also investigated. Optimal concentration and volume of PAM solution per hectare of bare sandy soil were determined. For this purpose a wind tunnel was used to determine wind velocities of the first and continuous detachment of particles. The ability of PAM application to minimize the damage of plants by sandstorms was experimentally verified using image analysis tools.

1. Introduction

The region of the western Negev desert of Israel is characterized by the vast areas of sandy soil with similar physical and hydrological properties: about 10% clay content, high infiltration rates and the very low amount (2–3%) of available water. The soil texture in combination with the shallow root penetration, or even a total absence of plant roots, creates conditions when soil can be easily transported by the wind. Consequently, this leads to the high frequency of sandstorms.

Young plants are among the first to suffer from sandstorms. The storms cause soil loss from the dry lands, and worse, they preferentially remove organic matter and the nutrient-rich lightest particles, thereby reducing agricultural productivity. Moreover, the abrasive effect of the storm, which is based on the mechanical impact of the saltating sand particles, damages young crop plants causing irreversible injuries of the plant leaves (Armbrust, 2001). Thus, the Vegetable Growers Association of Israel reported that the sand storm in the mid-December, 2010 in the Negev caused NIS 20 million ($5.5 million) worth of damage.

Currently, high frequency irrigation is used to prevent the wind damage of crops in Israel. Although such practice helps form a soil crust, it is associated with large waste of water, leading to additional soil erosion under arid conditions.

At the same time, application of polyacrylamide (PAM) as a chemical stabilizer proved to be highly effective to prevent the soil water erosion, to save irrigation water and to stabilize plant growth (Aase et al., 1998; Barvenik, 1994: Bjorneberg and Aase, 2000; Han et al., 2007; Roa, 1996; Sojka and Lentz, 1996; Teo et al., 2006). However, very little information is available about effectiveness of PAM for the prevention of the soil erosion by wind.

For example, Armbrust (1999) reports the results of PAM application onto the soil surface at 25, 50, 100, 200, and 400% of the recommended rate (5.6 kg/ha) and the recommended dilution (1:1000). Two types of soil (fine sandy loam and silty clay loam) after treatment with PAM were tested in a wind tunnel by exposing them to the wind speed of 13.4 m/s. Application of PAM to both soils revealed a dramatic reduction (up to 98%) of the loose erodible material. This reduction was practically independent on the amount of PAM applied in the range from 1.4 to 22.4 kg/ha.

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He et al. (2008) reported their results on the dry application of PAM to the loam and sandy loam soils. In their experiment they used three treatments of the soil samples packed in trays before setting them in the wind tunnel: (a) control (no addition of PAM), (b) 2 g/m^2 of PAM and (c) 4 g/m^2 of PAM were uniformly spread on the soil surface. Four soil water content levels from 3% to 9% were then reached for each treatment. The test in the wind tunnel at the wind speed of 14 m/s showed significant reduction of the erodible material for both soils in comparison with the control: 82% at the soil water content of 9% and 96% at the soil water content of 3% for loam; correspondingly 92% and 98% for sandy loam. The results were practically independent on the PAM concentration, i.e. for treatments (b) and (c).

These experiments and results suggested to test how effective was the application of PAM in low concentrations on sandy soil in order to reduce wind erosion and to prevent young crop plants from injuries by flying soil particles. For that reason, in this study there was investigated the ability of PAM to prevent sandstorms and to minimize the damage to plants in the region of the western Negev. Optimal concentrations and volumes of PAM solution applied to 1 ha of bare sandy soil were also determined. There were verified threshold wind velocities (TWV) for various PAM concentrations. In the wind tunnel there were determined TWV of first detachment (i.e. less than 2 particles per minute) and TWV of continuous detachment (when more than 3 particles in 15 s hit the sensor). Using image analysis tools there was found correlation between the PAM concentration applied on the test sandy soil and the damage of the experimental crop.

2. Materials and methods

2.1. Sample preparation

The experiments were conducted in a wind tunnel using typical sandy soil of the western Negev and young lettuce plants (*Lactuca sativa L. cv. "Noga"*). The soil granulometric composition, determined by sieving, is presented in Fig. 1.

The soil was placed into a tray with the dimensions presented in Fig. 2A. Then, the soil surface in the tray was evenly sprayed by 75 mL of PAM-water solution. The concentrations of the solution were: 0 mg/L (pure water), 62 mg/L, 125 mg/L, 250 mg/L and 500 mg/L. After the application of PAM, the samples were dried under a constant air flow for 24 h with the forming of crust on the soil surface. Non sprayed no-crust dry soil was also used in the experiment as a control.

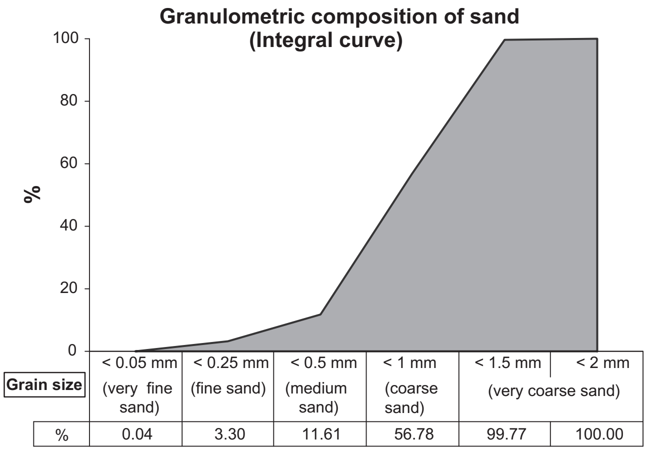

Fig. 1. Granulometric composition of the experimental soil (integral curve).

The plants were arranged in two rows inside a plastic tray (58 cm × 17 cm) divided into small compartments in order to separate individual plants and to provide the necessary distance of about 3 cm between them (Fig. 2B). For the plant damage analysis the leaves from the first row only were used, which corresponds to the natural conditions where the distance between plants is 25–30 cm and the screening effect is relatively small.

2.2. Wind tunnel setup

The samples of soil and plants were placed into the wind tunnel for test as shown in Fig. 2C. The wind tunnel was an open circuit with the 190 cm long test section (70 × 70 cm) and had the plexiglas roof and door. Its working length was 995.6 cm and its maximum speed reached 25–30 m/s. The wind velocities in the tunnel were measured by a Pitot tube connected to micromanometer (Argaman et al., 2006). The micromanometer was connected through a computer to a data logger which recorded the pressure measurements in mV.

The measurements in mV were translated to pressure units by calibration (Fig. 3).

The wind velocity in the tunnel was calculated by the known dynamic pressure. For this the standard equation for calculating velocity from velocity pressure (AIRFLOW Telescopic Pitot-Static Tube operating instructions 9020184/D/1095) was used:

$$U = 1.291\sqrt{\frac{1000}{B}\,\frac{T}{289}\,(P_t - P_s)} \tag{1}$$

where: U is wind speed (m/c); B is atmospheric pressure (mB); T is temperature (t °C + 273 K); $P_t - P_s$ is dynamic pressure (Pa).

TWV for each sample was determined as particles detachment activity monitored by SENSIT wind eroding mass sensor. Brief description of the sensor's characteristics: SENSIT allows examining high-resolution erosion activity. It responds linearly to the impacting kinetic energy of windblown particles. A minimum detectable particle diameter is difficult to estimate because of combined effects of mass, velocity and coefficient of drag. The sensor's response declines as a fifth-order function of particle diameter. This sharp decline function terminates the sensor's response at approximately 50 to 75 μm for low velocity particles. The sensor does respond to high velocity particles from 10 to 50 μm in diameter. Particles with the diameters of less than 10 μm tend to flow around the sensor due to the coefficients of drag.

Data acquisition was done by the same datalogger, counting the number of pulses of both outputs (wind speed and saltation impacts) for a selected sampling period. A pulse was produced for every particle impact of sufficient energy to trigger the particle count output circuitry. The output was the number of particle impacts. SENSIT was placed in such a way that its area of sensitivity (blue ring) was at the same level as the top edge of the plants to avoid the screening of the sensor by the plants during the experiment.

The wind speed in the tunnel was increased gradually from zero to maximum (about 27.5 m/s) during one minute each time. The total time of each test was 3 min.

The mean value of the flow density of soil grains was calculated as:

$$\mathrm{FD} = \frac{60\left(\sum_{i=1}^{t} n_i\right)}{S \cdot t} \tag{2}$$

where: FD is mean flow density of soil grains (SGN/min/cm^2); SGN is number of soil grains; t is time from the moment of constant particles detachment until the end of the experiment (s); S = 3.75 m^2 is the area of sensitivity of SENSIT; n_i is the number of SENSIT readings during the i-th second.