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Wind Tunnel Experiments on the Effects of Olives Mill Wastewaters Spray on the Reduction of the Entrainment of Sand by Wind

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Abstract

The degradation of physical characteristic of soils by wind erosion is one of major problem in the southern Tunisian arid regions. To find a remedy for these soils changes, studies were conducted, since many years, to reuse olives mill wastewaters, liquid waste produced in the process of olive oil extraction, like a simple and efficient practices for combating desertification. Wind-tunnel experiments were conducted on pre-treated soils with applied doses of 50 $m^3.ha^{-1}$, 100 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$ next to an a witness soil sample in order to investigate the effect of the mulching of olives mill wastewaters on reduction of wind erosion. Sand samples were exposed to different wind speeds for 2 min. Shear velocities were deduced from the wind speed profiles and saltation of sand particles was recorded electronically with a saltiphone©.

Within the 2-min test runs, changes in wind erosion aerodynamic parameters were detected. The aerodynamic roughness lenght, z_0, and the threshold shear velocity, u_{*t}, increase is proportional to the applied doses. The roughness lengths derived from the wind profile measurements measured over the various tested ranged from 1.78 E-04 and 3.92 E-04 m for 0 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$, respectively. The results in wind tunnel tests on the soil treated with these different doses showed that u_{*t} was raised from 8.65 $m.s^{-1}$ to 12.15 $m.s^{-1}$ for 50 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$, respectively. These results strongly suggest that the mulching of olives mill wastewaters reduces soil erosion by wind.

Keywords: olive oil wastewater; soil; wind tunnel; wind erosion.

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1. Introduction

Wind erosion occurs mainly in arid and semi-arid regions. Since a long time, many simple and efficient practices for combating desertification and wind erosion in the cultivated parcels were adopted. In Tunisia, different techniques have been achieved like the appropriate dimension of the plowed parcels, the optimal distance between the mail of windbreak, the spray of straw or the palm leaves in the soil surface, in particular in the parcel of olive tree, etc [12, 13]. The last decade, the research of simple and practical techniques had been oriented to reuse the liquid waste obtained after olive oil extraction process like an organic amendment for the structural stability improvement of the soil [1, 2]. Otherwise, the physical and chemical treatment and disposal of the large quantity of olives mill wastewaters remain one of the major environmental problems because of their high investment and maintenance cost [11, 16]. Indeed, In Tunisia 700.000 tons of olives mill wastewaters produced yearly. Similar situations can be found in the other countries where olive oil is produced (Spain, Greece, northern Africa and middle-east countries). The traditional system of olive oil extraction produces 400 l of liquid waste per 1 tone of olives; the tree-phase system produces 1 m3 of waste water per 1 tone of olives [4].

Field experiments were conducted in southern Tunisian arid zones in order to evaluate some improvement processes showed to the surface level and in depth after the mulching of olives mill wastewaters. In this region, both limited rainfall and weak soil structure favor wind erosion. This problem is reinforced in some cultivated areas due to repeated surface soil disturbances by tillage tools. Since 1996, 3 experimental plots of 1 ha each in olive orchards Chammakh -Zarzis (latitude 33° 35′ 40″ N; longitude 10° 59′ 34″ E), one of the largest olive-growing regions in Tunisia with more than 100,000 olive trees, was treated with different dose of olives mill wastewaters (50 $m^3.ha^{-1}$, 100 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$) next to a witness parcel without olives mill wastewaters (0 $m^3.ha^{-1}$).

In this paper we report results from wind-tunnel experiments conducted on pre-treated soil with olives mill wastewaters contents ranging from 0 $m^3.ha^{-1}$ to 200 $m^3.ha^{-1}$. For each plot, soil samples taken from the top 10 cm was used. The experimental results, which include aerodynamics parameters, threshold conditions and efficiency of liquid waste in reducing wind erosion, carried out in order to study the effect of applied doses of olives mill wastewaters on the reduction of soil erosion by wind.

2. Experimental procedure

Experiments were carried out in two stages. First we characterized, in wind tunnel experiments, the wind speed profile parameters and then we evaluated the effect of the liquid waste from the olive oil extraction on wind erosion reduction.

2.1. Soil samples

For each tested plot, soils were sampled from the upper 10 cm. The soil without olive mill wastewater (0 $m^3.ha^{-1}$) is classified as isohumic subtropical truncated soil, poor in soil organic matter (SOM) in [8]. A brief description and some analytical results for each treated soil are shown in table 1. The parent material is aeolian fine sand deposit generally lying on calcareous crust. They can be classified as cambic ARENOSOL in the FAO classification. Otherwise, as treatment with olive mill wastewater concerns only the top soil (the first 10 cm); it was considered that these plots do not show any differences. However, these results indicate certain heterogeneity particularly in edaphic features of soil in depth.

Table 1: Grain size (%) of soils samples collected in different depth on the experimental plots

Olives mill wastewaters doses ($m^3.ha^{-1}$)	0		50		100		200	
Depth (cm)	0 -15	15 - 45	0 -15	15 - 45	0 -15	15 - 45	0 -15	15 - 45
				Grain size (%)				
Clay	7.75	9.75	6	8.5	7.75	9	9	10.75
Silt	0.75	5.75	1.25	4.75	1	2	2	3.5
sand	91.04	83.87	91.87	85.83	89.94	89.14	82.75	80.33

The soil grain size is a fundamental property of sediment particles that plays an important role in sand drift and soil movement. In contrast to the classical approach used in sedimentology to characterise the soil texture, in assessing the soil size distribution as related to wind erosion processes, the size of soil grains must be determined without disturbance of the aggregates [5, 14]. This leads researchers to avoid disruptive techniques such as those involving wet samples when measuring the size distribution of soils erodible by wind. Dry sieving and dry dispersion laser particle size analysers remain the methods best suited to retrieving the size distribution of the soil aggregates with a minimum of disturbance. Key statistical parameters (median and standard deviation) are estimated by fitting the mass of sediment collected in each size class (i.e., in each sieve) to log normal functions. Indeed, as showed in [5], we assumed that the mass size distribution of an erodible soil can be estimated by the sum of log normal functions. This computation is performed by integrating the log-normal functions over the size range 1–2500 μm using 1300 iso-logarithmic size bins. These bins are then summed over the size interval corresponding to each of the 13 sieve classes. For this study, the samples were dried at 105°C during 24h before to be slowly sieved on a column of 13 sieves (<50, 50-75, 75-100, 100-125, 125-150, 150-200, 200-300, 300-400, 400-500, 500-600, 600-800, 800-1000, >1000 μm). The duration and intensity of the sieving were selected according various tests performed in order to define the best compromise allowing both a good classification of the grain size and no disruption of the aggregates. For our vibratory sieve shaker (Retsch©, AS200), the optimum conditions were obtained for 20 minutes of sieving with an intensity of 40. Each fraction was then weighted on an electronic balance having a precision of 0.01 g. The adjustment of the log normal distribution(s) is obtained using a least squares method, i.e., by minimising the sum of the differences between the measured masses for each class and those computed using the log-normal functions for the same classes. For these samples, the adjustment was made by using two modes (i.e., two log normal functions); the number of modes was selected using threshold values for the minimisation test (table 4).

2.2. Wind tunnel experiment

A closed-circuit blowing- type wind tunnel in the International Center for Eremology (ICE), situated at Ghent University, Belgium, with a 12 m long, 1.2 m wide and 3.2 m high working section, was used to evaluate wind profile parameters over soil treated with different dose of olive mille wastewater [9]. The boundary layer was set at about 0.60 m using a combination of spires and roughness elements [7]. The sand and soil samples were placed in 0.95 x 0.40 x 0.02 m trays, which were located at a distance x = 6.00 m downwind from the entrance of the wind-tunnel working section. The sample surface was smoothed and leveled to the test section false floor by drawing a straight edge across the sample surface. To ensure wind profile equilibrium with the roughness of the sample surface, the test section was covered with commercially available emery paper with the same roughness length as the surface of the sample, as determined experimentally from measured wind velocity profiles (fig. 1).

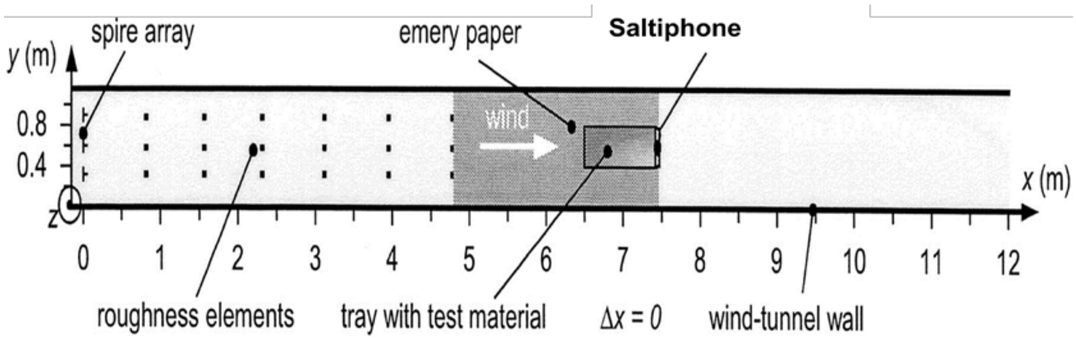

Figure 1: Schematic view of the wind tunnel and location of the tested sample

Wind velocity (u) was monitored at a 1-Hz frequency with 16-mm vane probes mounted at heights (*z*) of 0.02 m, 0.05 m, 0.105 m, 0.15 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m, 0.6 m and 0.7 m located at a downwind distance x = 5.85 m and a width y = 0.60 m. In neutral conditions, according to [15], Shear velocity (u_*) of the surface was calculated from the mean of wind velocity readings using a least-square fit to the well-known Prandtl–von Karman logarithmic law:

$$u_{(z)} = \frac{u_*}{k} ln \frac{z}{z_0} \quad (1)$$

where,

u(z): average wind velocity at height *z*;

k: Von Karman's constant (0.4);

z_0: aerodynamic roughness length.

The initiation of particle movement was determined by continuously recording particle transport with a saltiphone©, placed at x = 6.85 m, y = 0.60 m and z = 0.035 m, at shear velocities that are fluctuating around the threshold value. The saltiphone© is an acoustic sediment sensor that records the number of saltating particles that bounce against a microphone at a frequency of 0.1 Hz. The microphone is installed in a stainless steel tube. A potentiometer amplifies the high frequencies caused by the impact of sand particles, whereas it attenuates the low frequencies that characterize the noise caused by wind. Each particle impact produces a pulse that is cut off after 1 ms. A detailed description of the saltiphone© is given by [17].

3. Results and discussion

3.1. Wind speed profile parameters determination

Sand samples were exposed to wind speeds for 2 min. Wind velocity was determined by measuring the wind speed using a 16-mm vane probes. During each experiment, mean horizontal wind velocity was measured at ten heights from soil surface. In neutral conditions, the wind velocity profile in the inner boundary layer is described by a log-law (Eq. 1). Figure 2 provides an example of measured wind profile. Below 60 cm, two different regions can be observed: one associated with the internal boundary layer and other, following a log profile, associated with the ridged surface. Above 60 cm, flow tends to the free stream velocity.

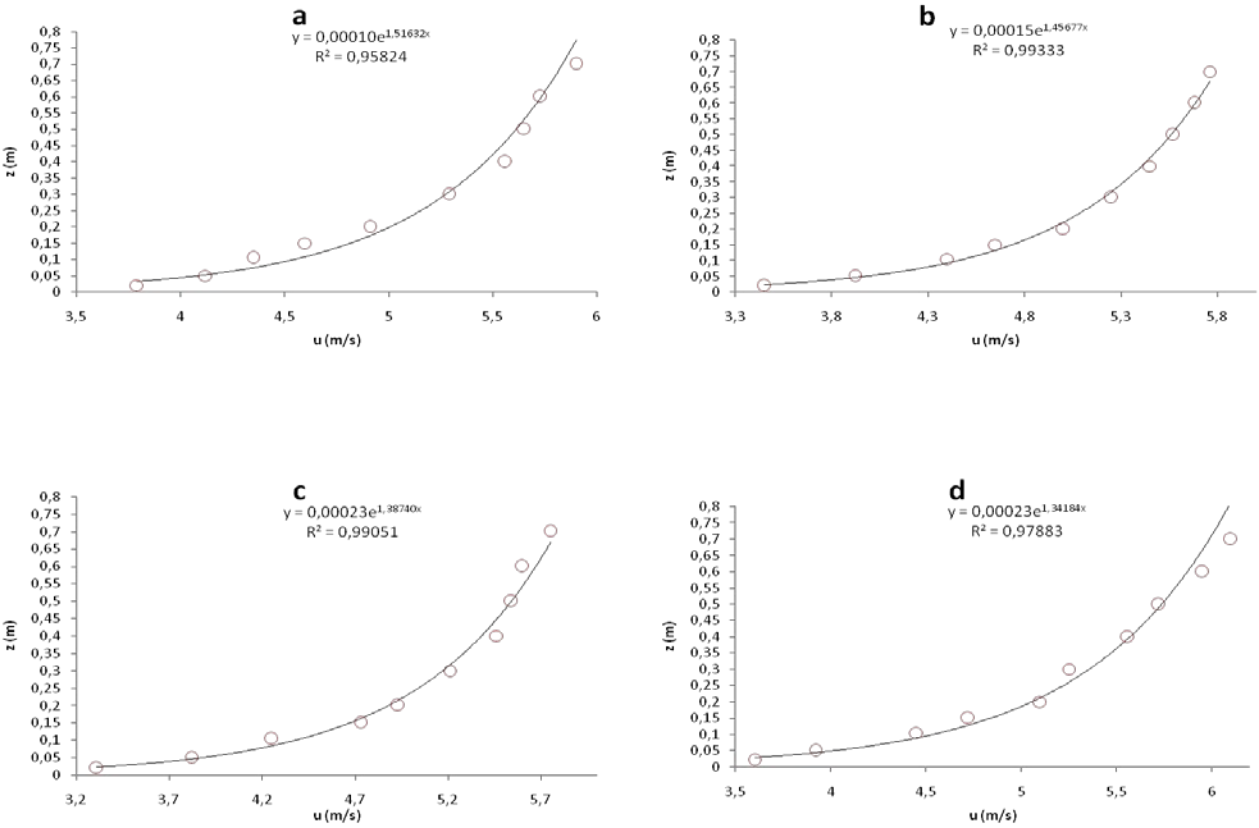

Figure 2: Measured wind velocity profile. Aerodynamic roughness length (z_0) is determined by fitting on the log-law profile (a: witness plot; b: plot with applied dose of 50 $m^3.ha^{-1}$; c: plot with applied dose of 100 $m^3.ha^{-1}$ and d: plot with applied dose of 200 $m^3.ha^{-1}$).

Measured wind profiles were used to determine the aerodynamic roughness length, z_0, and the friction velocity, u_*. The aerodynamic roughness length is introduced as a dimensional constant for the integration of the equation of the vertical profile. Numerically, it corresponds to the height above the surface at which the wind velocity reaches zero. It has been effectively widely used to assess the aerodynamic properties of sandy and various surfaces. Using this procedure, z_0 values ranged between 1.78 E-04 and 3.92 E-04 m for 0 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$, respectively (table 2).

Table 2: Aerodynamic roughness length (z_0) and wind friction velocity (u_*) for various soils treated with different olives mill wastewaters doses.

Olives mill wastewaters doses ($m^3.ha^{-1}$)	z_0 (m)	u_* ($m.s^{-1}$)
0	1.78 E-04	0.289
50	2.35 E-04	0.292
100	3.18 E-04	0.302
200	3.92 E-04	0.322

In this study, under similar conditions, soils treated with different doses are the only surface variables to be examined. The wind tunnel results of the aerodynamic roughness measurements, plotted in figure 3, show that spraying liquid waste could increase surface roughness of soil. Indeed, we observed that this wind speed profiles parameter on the plot treated with 200 $m^3.ha^{-1}$ was more than 2 time higher than this measured on the witness plot. When the surface roughness increases, a part of the wind shear stress is absorbed leading to a decrease of the soil losses due to wind erosion. These results could be explained by the increase of the organic matter in the soil, after the olives mill wastewaters spray, as indicated by [1, 2] which improve the cohesion between the soil aggregations and therefore structural stability.

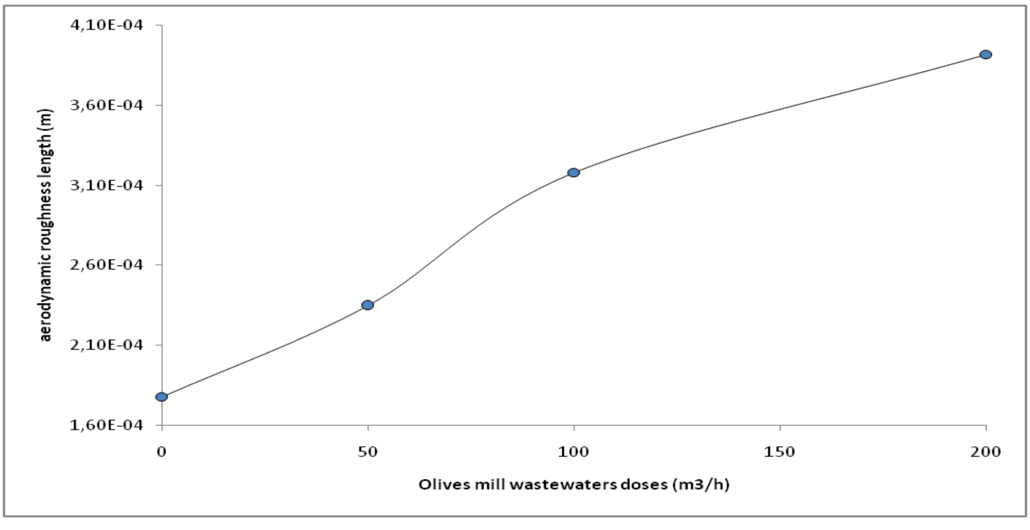

Figure 3: Change of aerodynamic roughness with olives mill wastewaters doses

3.2. Threshold friction velocity (u_{*t})

Particles start to move only if the aerodynamic destabilizing forces exceed the stabilizing forces that keep the particles together. In other words, for a given wind velocity and surface roughness, particles will be set in motion once the shear velocity u_* exceeds the threshold shear velocity u_{*t} which corresponds to the minimum u_* required to initiate erosion. This u_{*t} is mainly controlled by surface roughness (vegetation, clods, gravel, pebbles…), which absorb a part of the wind momentum needed to initiate particle motion, and soil characteristics.

A fast-response sensor was used to detect saltation of each soil sample tested in wind tunnel. The saltiphone© responds to particle impacts on the microphone and converts the responses to pulse. For each tested soils putted in the tray, we increased slowly the wind speed until first particles are recorded with saltiphone©. Once the wind erosion process has started, sand samples were exposed to wind speeds for 2 min. Otherwise, to avoid any change in the surface due to the saltation, the sand was removed after each 2 mn run, and the tray was filled again by the same. For each treatment with olive mill wastewater, 4 repetitions were conducted.

Experimental data including doses of olives mill wastewaters treatment (0 $m^3.ha^{-1}$, 50 $m^3.ha^{-1}$, 100 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$) and measured threshold friction velocity (u_{*t}) are reported in table 3. For the whole data, the wind velocity ranged from 8.50 to 12.15 $m.s^{-1}$. Obviously, for all the tested soils, u_{*t} increases with olives mill wastewaters doses: when liquid waste spray increases 2 times, the threshold shear velocity increases by a factor 0.20 and when we compare the plot treated with 50 $m^3.ha^{-1}$ to the plot which underwent a dose of 200 $m^3.ha^{-1}$, u_{*t} increases by a factor 0.40. These results can be explained by an increase in surface roughness which leads to an increase of the erosion threshold wind friction velocity. Aerodynamic roughness length, z_0, can be used as an integrative parameter to describe the effects of surface roughness on the erosion threshold.

Table 3: Experimental data for threshold friction velocities measurements

Olives mill wastewaters doses ($m^3.ha^{-1}$)	u_{*t} ($m.s^{-1}$)
0	8.502
50	8.651
100	10.259
200	12.156

In addition, wind tunnel experiments performed by [3, 6, 10] have noted the relationship between sediment grain size and the wind erosion threshold, i.e., the minimum wind velocity at which the soil particles begin to move. The statistical characteristics of the grain size are reported in table 4. The results of the sieving analysis revealed the essential commonalities and differences in erodible soil grain-size distributions for tested soil samples. When looking at the results of the fitting, we observed that all soil samples exhibited two size modes. The relative proportions of these two modes and their characteristics are very similar. When averaging, the 4 medians of the fine mode give a general feature i.e. a median diameter of approximately 100 μm. The systematic presence of a size mode near or below 100 μm, i.e., the grain size range requiring the lowest wind velocity to be mobilised [10], clearly indicates that these soils are highly susceptible to soil erosion by wind. Moreover, the fraction of the total mass that this fine mode represents is lower than 50% for all samples. However, the results of the sieving analysis showed also the presence of others populations, defined as the size modes more than 100 µm, whose diameter is proportional to the applied doses of olives mill wastewaters. Therefore, the size range of this population could increase the wind erosion threshold and thus reduce the erodability of these surfaces.

Table 4: Median (in µm), standard deviation and percentage of each mode constituting the mass size distribution of the soil samples collected on the experimental plots

Olives mill wastewaters doses ($m^3.ha^{-1}$)	0		50		100		200	
Mode	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2
Pi (Mi/M)	57.3%	42.7%	54.1%	45.9%	54.7%	45.3%	51.5%	48.5%
Sdt	1.24	1.06	1.20	2.01	1.19	1.24	1.23	1.12
Median (µm)	103.9	89.4	140.2	93.7	159.7	95.5	197.3	99.7

4. Conclusion

In order to evaluate different applied doses of 50 $m^3.ha^{-1}$, 100 $m^3.ha^{-1}$ and 200 $m^3.ha^{-1}$ next to a witness (0 $m^3.ha^{-1}$) of olives mill wastewaters on entrainment of sandy soil by wind, for soil samples, collected from for plots in olive orchards Chammakh -Zarzis (latitude 33° 35′ 40″ N; longitude 10° 59′ 34″ E), were experimented in wind-tunnel.

From these experiments, we measured wind speed profile parameters and additional experimental data on the threshold condition. The results of these experiments were then used to evaluate the efficiency of the applied doses of olives mill wastewaters in reducing wind erosion. Results show that, when compared to an untreated soil surface, the mulching of liquid waste obtained after olive oil extraction process lead to an increase of aerodynamic roughness length and threshold friction velocity. For each tested soil, maximum z_0 and u_{*t} occurs at treatment of 200 $m^3.ha^{-1}$. This implies that, aerodynamically, wind-eroded surfaces may become stable even when they are only partly covered by olive mill wastewaters. However, measurements from field experiments are required to confirm its consistency. Otherwise, a continually mulching of olive liquid waste in sandy soil, with these doses required more field measurements by monitoring their effect on the organic matter content, the soil permeability and the structural stability of soil. Finally, from a practical point of view, while these studies clearly demonstrate the efficiency of treatment in reducing wind erosion, direct applied mulching doses should be proposed.

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