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RESEARCH ARTICLE

Measurement of roughness lengths of ploughed soil by using a pin roughness meter

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Abstract

Surface roughness of cultivated soil that can be characterized by aerodynamic roughness length (z_0) has important implications to wind erosion. Field experiments were conducted in South Tunisia over two plots tilled with different ploughing techniques (mouldboard and tiller). The resulting surface is characterized by well marked ridges of different spacing and height. Measurements of soil surface geometric roughness were performed using a pin roughness meter.

Here we report results of the computation of aerodynamic roughness lengths by applying established relationships between z_0 and geometric characteristics of tilled ridges. These results suggest that parameterization could be used to estimate the aerodynamic roughness length induced by tilled surfaces when the geometric characteristics of ridges are known.

INTRODUCTION

Wind erosion is an important soil degradation process in semi-arid cultivated areas where conventional tillage continues to be used. Soil surface roughness created by tillage is an important feature that significantly affects soil erosion by wind over agricultural lands (Fryrear and Skidmore, 1985). Indeed, some tillage operations create random roughness by producing soil clods and aggregates. Other tillage operations create oriented roughness by producing soil ridges, which can trap saltating particles efficiently (Hagen and Armbrust, 1992). These geometric characteristics (ridges height (*RH*) and ridges spacing (*RS*)) can be considered the only soil roughness elements that help to reduce soil erosion by wind because vegetation cover is limited.

Otherwise, aerodynamic roughness length, z_0, can be used as an integrative parameter to describe the effects of surface roughness on the erosion threshold. Existing relationships between z_0 and geometric characteristics of tilled ridges have been established for a few ranges of ridge sizes. Indeed, to determine the aerodynamic roughness lengths created by ridged surfaces, many experimental studies have been conducted. In wind tunnel, Hagen and Armbrust (1992) performed experiments on armored ridges ranging from 2.37 to 15 cm in height and 21.5 to 326.1 cm in spacing. More recently, Kardous et al. (2005a) used a wind tunnel to measure z_0 of sandy soils over eight different ridged surfaces in terms of the ratio of ridge height to ridge spacing (*RH/RS*). Under field conditions, Saleh et al. (1997) measured z_0 for surfaces roughened with five different tillage implements: disc plow, moldboard plow, chisel and two types of lister. These authors, proposed to calculate z_0 based on *RH* and *RS*.

However, the surface roughness of ploughed soil is poorly documented in the literature. In particular, very few field measurements of geometrical characteristics of the surface are available for arid and semiarid regions. In this paper, we present results obtained during a field experiment performed in South Tunisia dedicated to measurements of the geometric surface roughness using a a 2m long pin roughness meter. Experimentation were conducted over surfaces tilled with different ploughing techniques leading to the formation of ridges of different spacing and heights. The results allow us to test the relationships linking these geometric characteristics to z_0 developed in wind tunnel by Kardous et al. (2005a).

2. Experimental procedure

2.1. Field experiment

The experimental field was performed inside the Dar Dhaoui Experimental Range (latitude 33°17’41”N, longitude 10°46’57”E) in Southern Tunisia, in the area of Medenine, a semi-arid region where annual precipitations are low (≈ 200 mm.year^{-1}) and irregular in space and time, most of the rainfall falling in autumn and winter. Inside this range, two parcels of 1.8 hectares each have been ploughed perpendicularly to the prevailing direction for the highest wind velocities. Different ploughing techniques were used on the two parcels in order to investigate the aerodynamic roughness length over surfaces having ridges of different spacing and height. The resulting surface is characterized by well marked ridges.

The mouldboard plough was composed of 6 elements. Its working width is 2.3 m and its depth of cut is about 15 cm. This ploughing tool cuts soil slices by its wedge-shaped body, lifts it with its mouldboard (inclined plane) and inverts it gently burying the weeds and crop residues. Mouldboard plough produces well-marked ridges. The operating mode was soft, with a low tractor speed (3-4 km.h^{-1}), leading to well marked ridges, comparable in shape and size to those obtained with North African traditional plough (figure 1).

The tiller plough is suitable for use in stone and root obstructed soil and for light and medium soil conditions. It is used for loosening and aerating soil to a depth of about 20 cm. The tiller used was constituted by 2 lines composed of 6 and 7 tynes respectively, leading to a working width of 3 m (figure 1).

2.2. Geometric characteristics of ridges

Obviously, the top layer of the soil (up to 10 - 12 cm) is significantly disturbed by the ploughing tools and the surface features of each parcel are strongly different after ploughing. The characteristics of ridges were determined using a 2m long pin roughness meter composed of 400 pins, each having a height of 29 cm mounted on a horizontal spindle 200 cm wide that can move vertically (figure 2). When the pin roughness meter is placed in a vertical position (working position), pins, which are 5 mm apart, based on the soil surface by following rigorously the microrelief. The upper edges of pins (which describe the microrelief) are photographed in each measurement. The photographs obtained are then processed to derive the geometric characteristics of the ploughed soils.

In order to use the pin roughness meter on newly plowed experimental plots and where the soil, freshly stirred, has a most importantly pore volume, measures feasibility tests have been previously performed. These tests showed that pins of the pin roughness meter tend, under the influence of their own weight, to sink in more or less deeply into the soil making difficult to measure the geometrical characteristics of the ploughed soils. To overcome this disadvantage, a countersunk screw was mounted on the feet of each pin (figure 3) to increase the contact surface with the soil and therefore distribute the pressure exerted by each pin on the soil. Visually, this change has significantly improved the quality measurements.

In each parcel, at least ten 2 m-profile measurements were performed. The profiles were imaged numerically and statically treated to retrieve the median height and spacing of the ridges.

In addition, experiments conducted to determine the relationship between z_0 and geometric characteristics of tilled ridges provide estimates of z_0 from a broad variety of ridge characteristics (Hagen and Armbrust, 1992 ; Saleh et al., 1997 ; Kardous et aal., 2005a). In agreement with previous studies, results from Kardous et al., 2005a, show that the aerodynamic roughness length over ridged surfaces can be related to the geometric characteristics of the ridges:

$$z_0 = 1.2736 \cdot \frac{RH^2}{RS} - 0.005 \tag{1}$$

With RH and RS are height and spacing of the ridges respectively and z_0 aerodynamic roughness length. z_0, RH and RS were expressed in meters.

Using Eq. (1) and the measurements of the geometric characteristics of the ridges, we computed the aerodynamic roughness length for each tilled surface.

3. Results and discussion

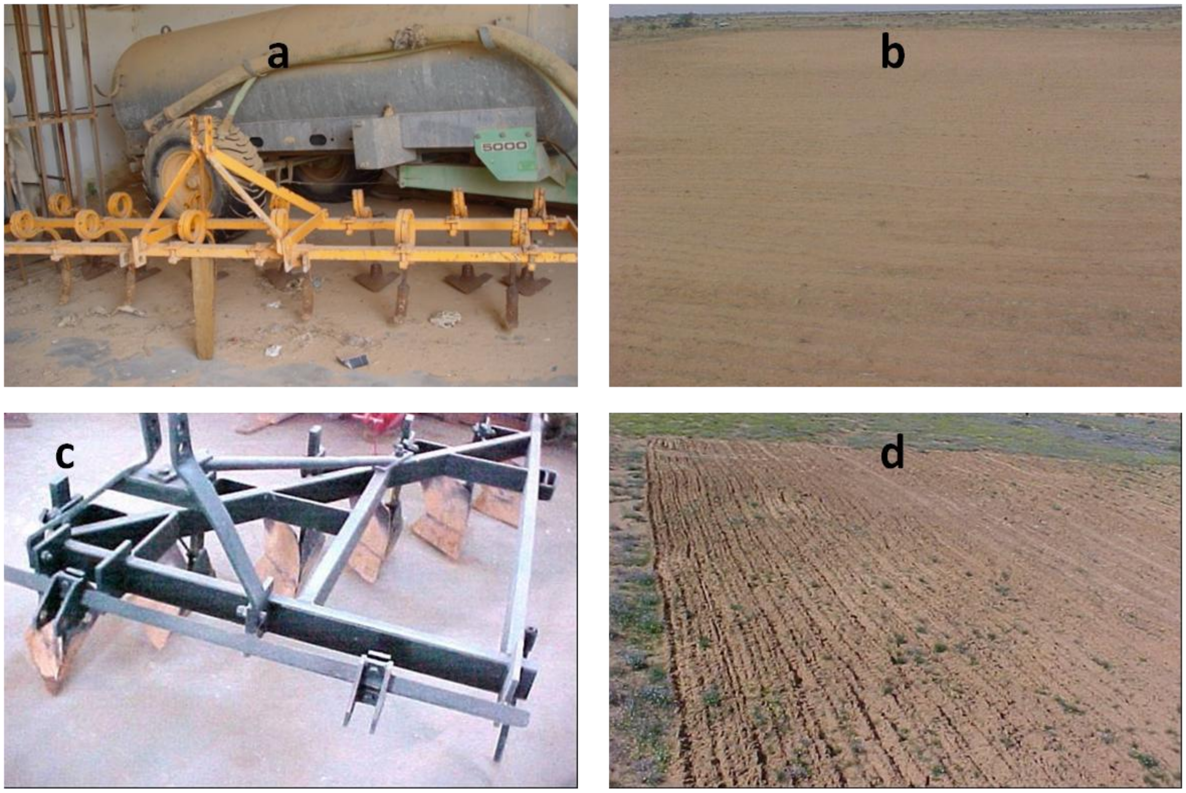

Figure 1: Different ploughing tools used and their corresponding ploughed surfaces: (a) the tiller plough; (b) soil tilled with a tiller; (c) the mouldboard plough and (d) soil tilled with a mouldboard.

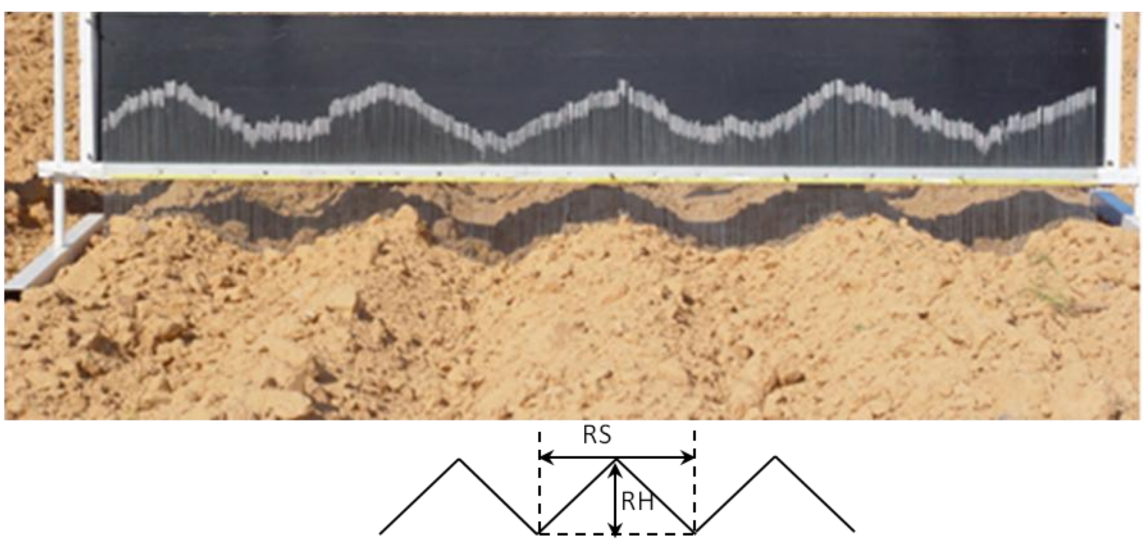

Figure 2: General view of the pin roughness meter used to characterize the plowed surface (on top). Ridges geometric characteristics: Ridges spacing (RS) and ridges height (RH) (below).

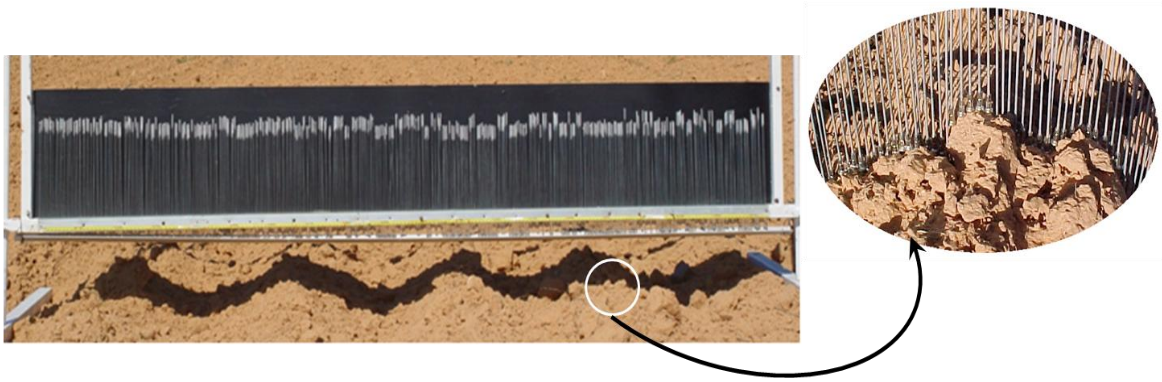

Figure 3: General view of the pin roughness meter used to characterize the plowed surface. Left: the pin roughness meter in the rest position, right: detailed view of the pins.

3.1. Height and spacing of ridges

Measurements of soil surface geometric roughness were performed in Dar Dahoui using a pin roughness meter. The results of measurements performed just after the ploughing indicate that both plots ploughed with the mouldboard and the tiller plough exhibited well defined ridges (figure 4). On the parcel ploughed with the mouldboard, the ridges were 7.7 cm (+/- 1.6 cm) and 53.7 cm (+/- 6.5 cm) respectively. While, mean values of *RS* and *RH* obtained on the plot ploughed with the tiller by this method were 8.5 cm (+/- 1.3 cm) and 45.8 cm (+/- 4.8 cm) respectively.

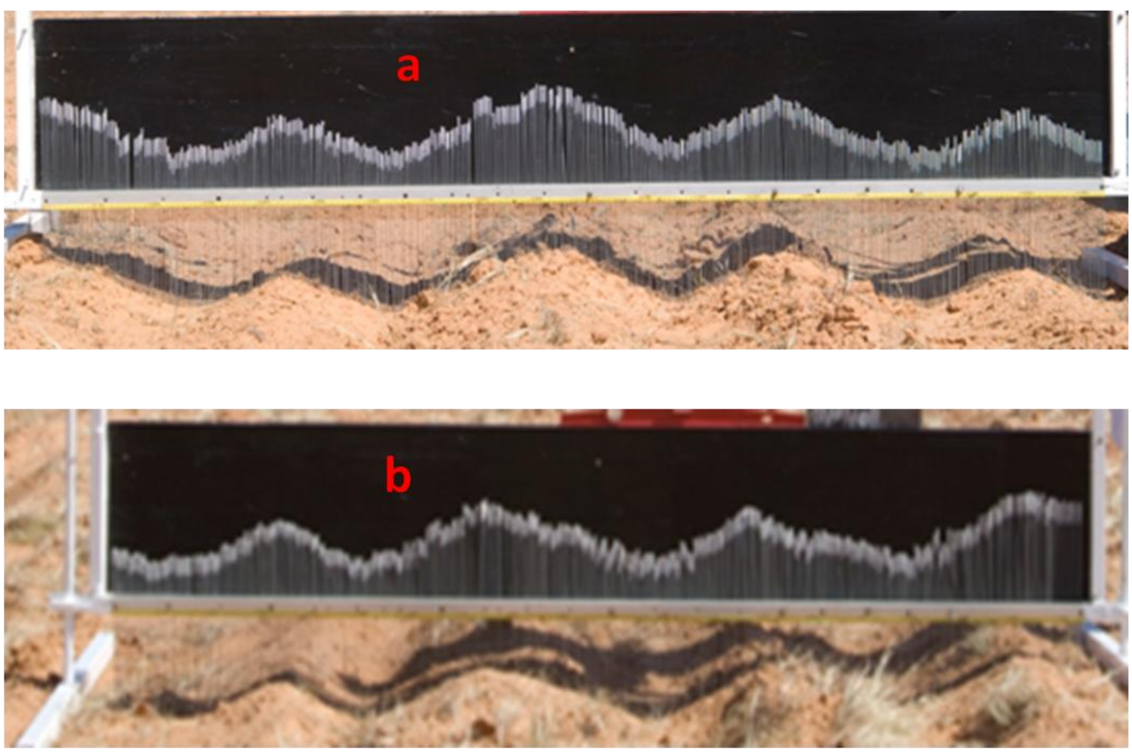

Figure 4: a: The pin roughness meter in working position in the plot ploughed with a tiller; b: the pin roughness meter in working position in the plot ploughed with a mouldboard.

3.2. Aerodynamic roughness length

Using the measurements of the geometric characteristics of the ridges we computed with equation 1, the aerodynamic roughness length for each tilled surface. Results are reported in figure 5. The computed z_0 range over 0.9 cm and 1.51 cm for plots ploughed with the mouldboard and the tiller plough, respectively. These values correspond well with the range of aerodynamic roughness lengths measured in a wind tunnel by Kardous et al. (2005a) for ridges with a similar *RH/RS* ratio (z_0 = $1.38.10^{-2}$, $1.44.10^{-2}$ and $2.1.10^{-2}$ m, respectively, for RH/RS ratios of 0.21, 0.18 and 0.22). As expected due to the presence of ridges, these values also fall in the upper range of aerodynamic roughness lengths measured over arid and semi-arid surfaces, which vary from $4.10^{-}5$ m to 7.10^{-2} m (Marticorena et al., 2006). The results of these calculations show that this parameterization reproduces quite well the order of magnitude of the measured aerodynamic roughness lengths in both wind tunnels and field conditions.

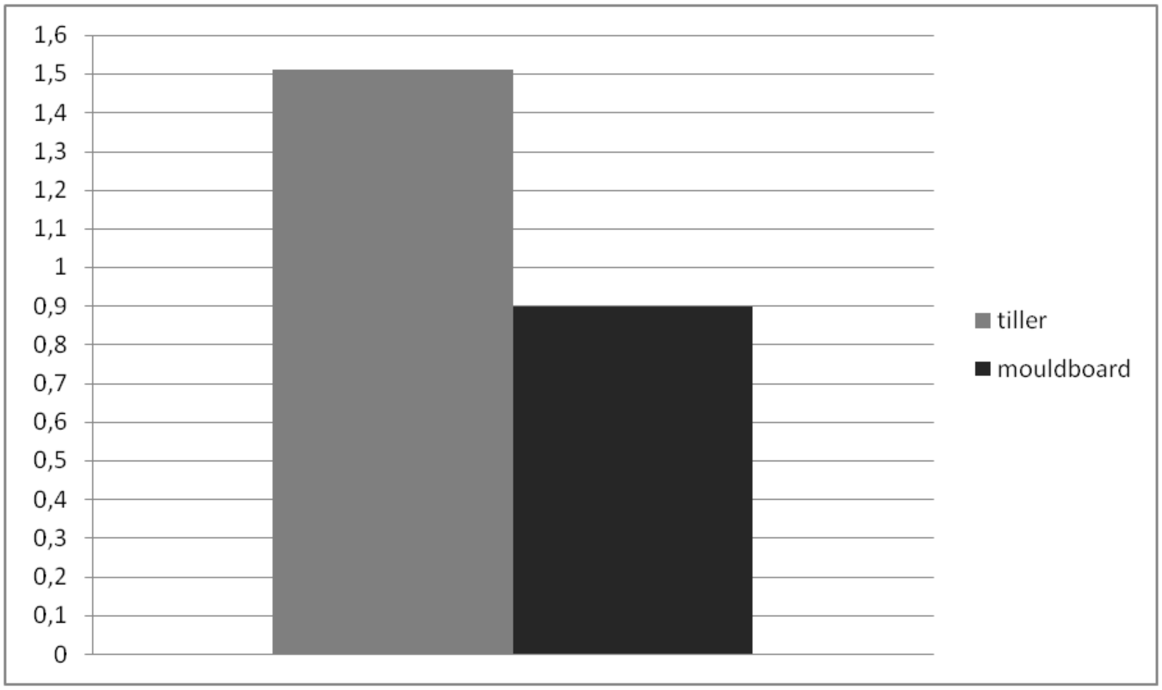

Figure 5: Computed roughness height (z0) for ridged parcels.

According to the limited accuracy of the measurements (as illustrated by the large standard deviations associated to the mean), these results suggest that the roughness lengths measured during this campaign is not statistically different. This is quite surprising since the surfaces were ploughed by using different tools which produced surfaces having ridges of different height and spacing. However, we have to keep in mind that the measurements of z_0 performed in wind tunnel by Kardous et al. (2005a) for ridges having very different characteristics exhibited only a factor 3 between the lower and the larger measured z_0. Whatever, additional precise measurements of aerodynamic roughness length over tilled surfaces remain necessary.

4. Conclusion

Existing relationships between the aerodynamic roughness length (z_0) and geometric characteristics of tilled ridges well adapted to roughness resulting from ridges observed in agricultural soils of semi-arid North-Africa have been established. Measurements were made in South Tunisia inside parcels tilled with different ploughing tools (mouldboard and tiller). The ridges spacing *(RS)* and ridges height *(RH)* were determined by using a pin roughness meter.

The computation of roughness lengths performed using Kardous et al (2005a) parameterization indicates that the method used, despite its simplicity, reproduces the measurements well, regardless of surface type. However, tests have indicated that the parameterization is especially sensitive to the precision at which the geometric characteristics of the ridges are determined, indicating that in any application, special attention should be given to this point. Otherwise, the application of the proposed linear relation in different scientific studies (local erosion assessment) may therefore be considered. It could be also useful in designing and recommending tillage tools that reduce the soil susceptibility to wind erosion in semi-arid regions.

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