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Evaluation of surface roughness parameters in agricultural soils with different tillage conditions using a laser profile meter

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ABSTRACT

Surface roughness crucially affects the hydrological and erosive behaviours of soils. In agricultural areas surface roughness is directly related to tillage, whose action strongly affects the key physical properties of soils and determines the occurrence and fate of several processes (*e.g.*, surface storage, infiltration, *etc.*). The characterisation of surface roughness as a result of tillage operations is not straightforward, and numerous parameters and indices have been proposed for quantifying it. In this article, a database of 164 profiles (each 5 m long), measured in 5 different roughness classes, was analysed. Four roughness classes corresponded to typical tillage operations (i.e., mouldboard, harrow, seedbed, *etc.*), and the fifth represented a seedbed soil that was subject to rainfall. The aim of the research was to evaluate and select the surface roughness parameters that best characterised and quantified the surface roughness caused by typical tillage operations. In total, 21 roughness parameters (divided into 4 categories) were assessed. The parameters that best separated and characterised the different roughness classes were the limiting elevation difference (*LD*) and the Mean Upslope Depression index (*MUD*); however, the parameters most sensitive to rainfall action on seedbed soils were limiting slope (*LS*) and the crossover lengths measured with the semivariogram method (l_{SMV}) and the root mean square method (l_{RMS}). Many parameters had high degrees of correlation with each other, and therefore gave almost identical information. The results of this study may contribute to the understanding of the surface roughness phenomenon and its parameterisation in agricultural soils.

1. Introduction

Surface roughness is a key element in the hydrological and erosive behaviour of soils (Helming et al., 1998), and as a soil-atmosphere frontier, plays an important role in many processes, such as infiltration, runoff, the detachment of soil due to water or wind, gas exchange, evaporation and heat fluxes (Huang and Bradford, 1992).

Depending on the order of magnitude of the soil surface elevation variations, and on the spatial arrangement of its microforms, surface roughness can be classified into different categories (Römkens and Wang, 1986): (1) Variations in the soil's microrelief due to its individual particles and/or microaggregates (variations of the order of 1 mm, but up to 2 mm). (2) Variations in the surface generated by soil clods caused by agricultural practices (variations of the order of 100 mm, but up to 200 mm); these two roughness types are considered random and isotropic (i.e., uniform in all directions). (3) Roughness due to the systematic differences in elevation (i.e., rows or furrows) caused by tillage implements (variations between 100 and 200 mm); these forms are one-directional and this component is, therefore, oriented or anisotropic. (4) Roughness due to the macroforms of the terrain (of the order of several meters), which together define the topography of the landscape; these elevation variations are usually non-directional. Although the classification of Römkens and Wang (1986) associated the effect of tillage with an oriented type of roughness (category 3), it is understood that random roughness (categories 1 and 2) is also affected, to a greater or lesser extent, by tillage.

The order of magnitude in the elevation variations of the two (or three) first roughness types is lower than the spatial resolution of the digital elevation models that are conventionally used (Govers et al., 2000; Mushkin and Gillespie, 2005). Hence, in order to quantitatively characterise those microforms, it is necessary to take complementary measurements *in situ*, which permit the calculation of different surface roughness parameters or indices.

The parameterisation of the random surface roughness caused by tillage (the first two categories cited above) is not straightforward. Each tillage practices (or implements) causes, in theory, a

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particular type of microrelief under identical soil conditions (in terms of texture, moisture, density, *etc.*). Considering the wide range of possible soil conditions, a huge variety of roughness types could be found in agricultural soils immediately after tilling. In addition, soil physical properties, particularly surface roughness, can also be highly variable in space. To further complicate its characterisation, surface roughness also shows a multi-scale nature making any roughness measurement scale-dependent (Zhixiong et al., 2005; Verhoest et al., 2008; Álvarez-Mozos et al., 2011). Finally, the microrelief generated by the different tillage practices is more or less susceptible to change throughout time due to the action of meteorological agents, *e.g.*, precipitation (Dalla Rosa et al., 2012), wind and temperature changes in the low atmosphere (Pardini, 2003), or even animal activity.

Although there are many parameters and indices for quantifying surface roughness (*e.g.*, Helming et al., 1993; Magunda et al., 1997; Kamphorst et al., 2000; Vermang et al., 2013), none work universally and interested scientists/technicians find it difficult to select the most appropriate one for their particular case. The random roughness parameters that are most commonly used in the literature, described in section 2.3, were considered in this study; these parameters can be divided into four groups, following a criterion similar to that of Smith (2014): (1) parameters measuring the vertical dimension of roughness or the magnitude of the elevation variations of the points at the soil surface (vertical parameters), (2) parameters measuring the horizontal dimension of roughness or the relation between the height of a point and that of its neighbours (horizontal parameters), (3) parameters combining both dimensions (combined parameters), and (4) parameters based on fractal theory, which measure self-affinity or the balance between height variations at different spatial scales (fractal parameters).

In light of the above, the aim of this research was to evaluate and select the most appropriate surface roughness parameters to characterise and quantify the surface roughness caused by typical tillage operations.

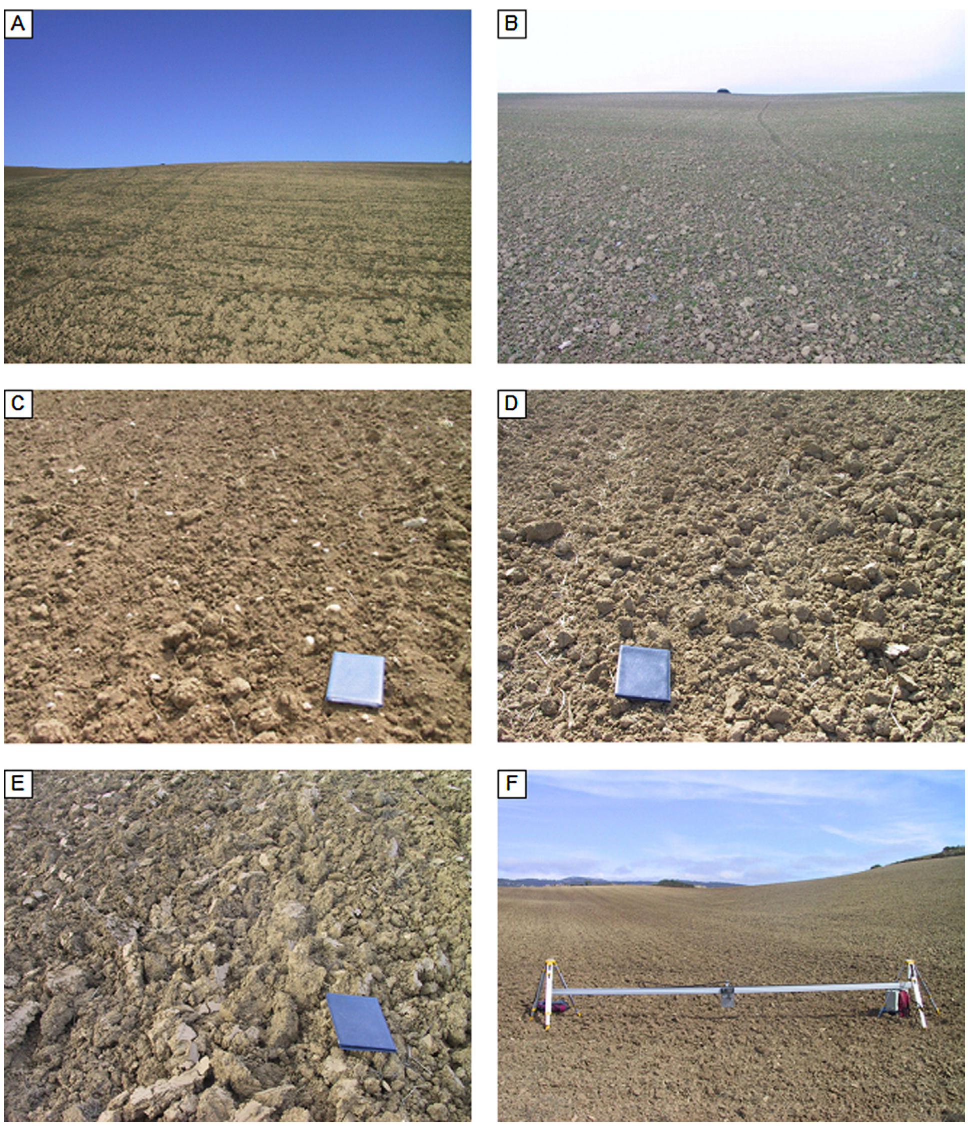

Fig. 1. Examples of surface roughness triggered by agricultural treatments; (A) planted modified by rainfall, (B) planted unmodified, (C) harrowed smooth, (D) harrowed rough and (E) mouldboard plough; and (F) profilometer used for data taking. As a reference, the notebook in C, D, and E is 30 cm long; and 5 m the length of the profilometer bar in F.