

Estimating soil roughness indices on a ridge-and-furrow surface using stereo photogrammetry

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Abstract

The paper deals with the quantitative characterization of small-scale random roughness on agricultural bare soils which controls many of the hydraulic and erosion processes on the field scale. More precisely, our aim is to analyse the adequacy of a stereo photogrammetry system to obtain accurate estimation of this random roughness by means of statistical parameters and to detect soil surface roughness changes due to rainfall.

The work presented in this paper is based on a set of digital elevation models (DEMs) of actual agricultural bare soils obtained by stereo photogrammetry. The considered field surfaces correspond to various tillage practices (conventional seedbed, chisel and conventional ploughing) and are watered by simulated rainfalls in order to get various patterns.

The stereo photogrammetry process is carefully analysed; the effects of the correlation window size are taken into consideration in order to propose optimized DEM reconstructions.

Classical roughness parameters such as root mean square of the heights, correlation length and tortuosity are estimated on the DEMs of the database and results concerning the effect of the DEM size on the obtained accuracy are presented for each roughness parameter. The tortuosity comes out to be a relevant roughness estimator able to quantify the roughness evolution during rain, even with important degradation of the soil.

Finally to study the evolution of roughness with rainfall thoroughly, we introduced two positional tortuosity values computed independently over the areas of ridges and interrows of the DEM. The obtained values clearly show that the rainfalls do not decrease homogeneously the soil small-scale roughness: the interrows areas are much more smoothed by the rain than the ridges areas do.

The study presented shows that stereo photogrammetry provide DEMs that enable accurate studies of the geometrical properties of soils that can definitely be of use for hydraulic and erosion studies.

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1. Introduction

The soil surface microtopography – or roughness – is strongly influenced by agricultural activities, together with soil properties and climate. Tilled surface can be seen as the superposition of a large-scale periodic

topographic variation or oriented roughness (identified with the rows) and a non-orderly spatial distribution (named random roughness) of clods of various sizes, aggregates and grains on the surface. The soil surface roughness that controls most of the hydraulic and erosion processes on the field scale undergoes rapid changes caused by the tillage operations, followed by a slow evolution of the soil structures due to rainfall. To predict the routing of runoff over the landsurface from the whole field scale up to the catchment scale, as well as to identify the local contributing areas and erosion

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patterns, hydrologic and erosion models use physically based mathematical relationships that describe the transfer processes of soil and water on and across the surface boundary of soil. Among the variables commonly used to quantify these phenomena, the surface depression storage and the hydraulic resistance which controls the flow velocity (usually the Manning coefficient or the Darcy-Weisbach friction factor) are directly influenced by the soil roughness.

Until recently, the roughness was mainly described by two indexes: namely the random roughness RR (Allmaras et al., 1966; Currence and Lovely, 1970) and the tortuosity T_B (Boiffin, 1984) that have been both connected to the depression storage in a quite successful way (Onstad, 1984; Ullah and Dickinson, 1979; Morgan et al., 1998; Govers et al., 2000; Kamphorst et al., 2000). But, as reported by Huang and Bradford (1992) and many studies (Linden and Van Doren, 1986; Bertuzzi et al., 1990), roughness is a function of scale and a descriptive model for soil roughness should have scale-dependent characteristics. The quantification of roughness with scale was hindered during a long time by the poor-quality of elevation datasets due to laborious field techniques (pin-profiler) that produced only low-resolution data. A major progress has been made by the recent availability of more detailed surface-elevation data at (sub)-millimeter grids obtained by laser scanners (Huang and Bradford, 1992; Bertuzzi et al., 1990; Eltz and Norton, 1997; Darboux and Huang, 2003) and photogrammetric stereovision systems (Jeschke, 1990; Helming et al., 1992; Zribi et al., 2000a) which allows to analyse the spatial organisation of the surface. Two-dimensional random processes were used to describe it. Due to the finite amount of available data, only the first and second order statistics of the surfaces are commonly considered: explicitly their probability density function and their spatial-correlation structure which can be expressed by the covariance function. As an example, Huang and Bradford (1992) suggested to describe soil roughness by a Markov–Gaussian type random process, with an exponential-type correlation function. They introduced two statistical parameters (the global variance which is related to the random roughness value and the correlation length scale) to parameterise the depression storage. They additionally established that the depression storage estimation is dependent on the grid spacing which determines the cutoff limit of the small-scale variation description.

For interrill overland flow relatively little work has been done to relate the hydraulic resistance of the surface directly to its microtopography. Though Gilley

and Finkner (1991) established two empirical relationships connecting the hydraulic resistance to the random roughness and to the flow Reynolds number, this hydraulic resistance appears to be related in a complex way to the soil surface microtopography: actually, on a rough tilled surface, water flow concentrates between the clods, routing the runoff in many flow lines on a portion of the surface that depends on the water depth. In a recent study, Takken and Govers (2000) proposed a model to predict the hydraulic resistance of the surface which takes into account the spatial distribution of the flow over the surface, as well as the roughness within the flow. To do that, they had to introduce the tortuosity value of the submerged part of the surface. This last example shows that a single global roughness index of the soil surface is not adequate in the case of rough elements progressively inundated with water. The roughness of sub-parts of the tilled surface has to be taken into consideration.

These different studies show the importance of making use of high-resolution topographic data sets in millimeter grids to derive high accuracy measurements of the statistical scale-dependent characteristics of the surface roughness and to obtain indices over sub-parts of the surface.

Even if stereo photogrammetry is not yet as usually used for high-resolution topographic measurements as laser scanners, it becomes more intensively employed with the progress of CCD-cameras performances and the development of more reliable and userfriendly methods for automatic stereocorrelation. It is commonly accepted that photogrammetry provides digital elevation models (DEMs) in millimeter grids with a positional accuracy comparable with laser-scanned DEMs one but with an elevational accuracy which does not reach the sub-millimeter accuracy of the laser devices. The overall objective of this study is to analyse the adequacy of a stereovision system to obtain accurate measurements of statistical surface variables and to detect soil surface roughness changes during rain. The work presented here is based on DEMs of actual field surfaces corresponding to various tillage practices (conventional seedbed, chisel and conventional ploughing) watered by simulated rainfalls, where the soil surface went from an initial loosely cloddy condition to a consolidated crust.

Huang and Bradford (1990) have shown that, for surface topography, any variable is controlled not only by the global statistics, but also by the upper and lower cutoff length scales of the DEM. In stereo photogrammetry technique, the DEM is computed from two digital images of the same spot taken with two cameras

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