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Can infrared thermography be used to estimate soil surface microrelief and rill morphology?

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ABSTRACT

This study presents a new technique to estimate soil surface microrelief and rill morphology using infrared thermography. This technique can be specifically useful to characterise soil surface microrelief to identify preferential flow paths in mulching conditions and to estimate soil surface elevation where other microrelief measurement techniques cannot be successfully applied. Laboratory tests were carried out using two soil flumes where different conditions were tested: with artificial rills created at the soil surface and with a surface eroded by flowing water. The technique was tested both in bare soil conditions and in the presence of different mulching surface cover densities. Heated water was used to create a temperature gradient on the soil surface and high resolution soil surface thermal imaging was obtained using a portable infrared video camera.

The proposed technique allows us to identify different microrelief structures at the soil surface and to visualize preferential flow paths in mulching densities up to 4 ton/ha. Where other microrelief measurement techniques cannot be used, the thermography allows to obtain 3D models of the soil surface elevation, with satisfactory accuracy. Higher mulch cover densities (above 4 ton/ha) strongly affected the performance of the technique.

1. Introduction

Microrelief is the spatial arrangement of the micro-topographic variations in soil surface elevation at a scale ranging from centimetres to millimetres or less (e.g. Huang, 1998; Paz-Ferreiro et al., 2008; Vidal Vázquez et al., 2005). It is the result of several factors that affect the superficial layer of the soil over time, such as: water erosion (e.g. splash, interril and rill erosion), wind erosion, agricultural practices (e.g. tillage, ploughing, mulching), vegetation (e.g. roots, mulch, shrubs, grass) and animal activity (e.g. ant mounds).

Microrelief is not static. One problem related with the modelling of runoff-erosion processes and rill erosion models is the effect of change in microrelief over time and area in which those processes occur (e.g. Zobeck and Onstad, 1987). Erosion processes modify the soil surface and create a new specific surface. For example, runoff during the last part of an event will flow over a soil surface that is different from the surface encountered earlier in the storm (e.g. Favis-Mortlock et al., 2000). Also, larger rills will modify the local micro-topography in a greater extent than small rills. Therefore, microrelief and runoff-erosion processes are interconnected (e.g. Favis-Mortlock, 1998).

Microrelief has been demonstrated to strongly influence several hydrological processes, such as infiltration, runoff, sediment transport, rill formation, rill erosion (e.g. Darboux et al., 2001; Gómez and Nearing, 2005; Kidron, 2007; Römkens et al., 2001), surface sealing, surface crusting and soil moisture (e.g. Fohrer et al., 1999; Rodríguez-Caballero et al., 2012), evaporation and heat flux (e.g. Price et al., 1998). Most of the time, modelling those processes requires detailed information on soil surface microrelief (e.g. Govers et al., 2007; Kamphorst and Duval, 2001; Kamphorst et al., 2000; Lei et al., 1998; Mancilla et al., 2005; Nearing, 1998; Planchon et al., 2001).

A wide range of techniques can be used to characterise and measure the soil surface microrelief and rill morphology (e.g. width, depth) with an adequate resolution and precision for water erosion studies and modelling. Yet, this task may require a large consumption of time and/or resources (e.g. Jester and Klik, 2005). Measurement techniques can be classified according to the sensing type as contact and noncontact techniques. The most common contact techniques, used to characterise soil surface roughness, are: profile or pin metres (e.g. Gilley and Kottwitz, 1995); chain and set methods (e.g. Merrill et al., 2001); and automatic relief metres (e.g. Hansen et al., 1999). The principal benefits of these techniques are the low cost and easy handling. However, these techniques have limited resolution and may induce deformation to the soil surface. Nowadays, there are very accurate noncontact techniques that allow the generation of digital elevation models with enough resolution for microrelief and rill analysis, being the most commonly used: laser techniques (e.g. Darboux and Huang, 2003; Eitel et al., 2011); and photographic techniques such as photogrammetry methods (e.g.

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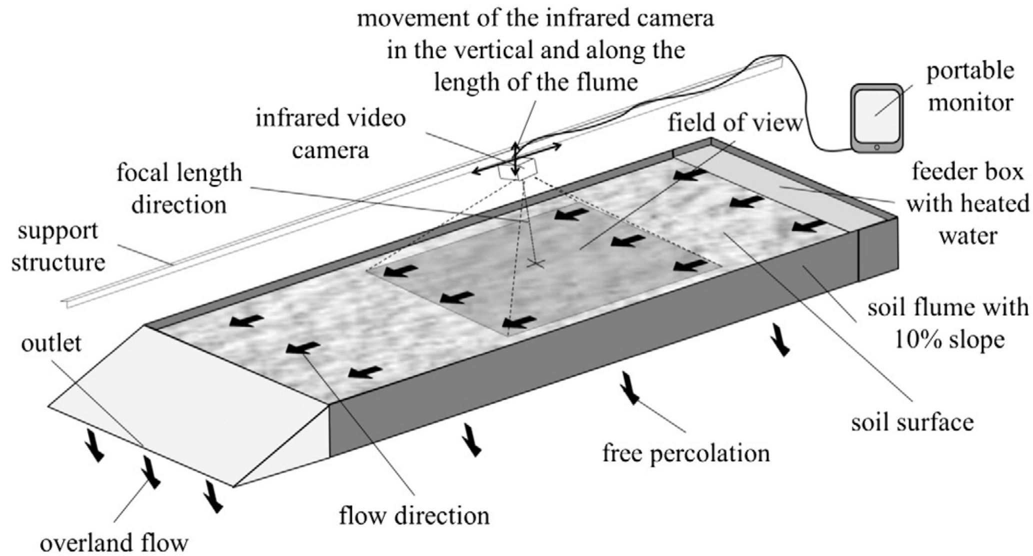

Fig. 1. Sketch of the setup used in the laboratory tests (not at scale).

Rieke-Zapp and Nearing, 2005; Warner, 1995) and shadow analyses (Moreno et al., 2008). One of the main problems associated with the noncontact techniques is the presence of mulch covering the soil surface, as it strongly affects the accuracy of the microrelief measurement. In fact, with high mulching covers microrelief cannot be estimated by these techniques, since they measure the mulch surface roughness instead of the soil surface microrelief bellow.

In agricultural and rural areas of arid and semiarid regions, water erosion is one of the most important soil degradation processes (e.g. Cantón et al., 2011; Martinez-Mena et al., 2001; Mayor et al., 2009). Runoff-erosion modelling is of great significance to improve soil and water conservation management in those regions (Hessel and Tenge, 2008). One of the main problems when assessing information on soil surface microrelief for water erosion studies in agricultural semiarid environments is the presence of vegetation covering the soil surface (i.e. mulching) that is one of the most used soil and water conservation methods in those areas (e.g. Montenegro et al., 2013; Totin et al., 2013). In fact, with high mulching covers microrelief cannot be estimated by these techniques, since you measure the mulch characteristics instead of the soil surface bellow.

This paper presents an innovative technique to estimate soil surface microrelief and rill morphology using infrared thermography. This has been done through controlled soil flume experiments. Infrared thermography has been successfully applied as a high resolution imaging tool in hydrological studies: surface water temperature distributions (e.g. Danielescu et al., 2009) and groundwater–surface water interaction (e.g. Mejías et al., 2012). In particular, studies carried out with portable hand-held thermography systems have been recently increasing, due to their easy handling and adjustment of measurement distance and scale (e.g. Cardenas et al., 2008; Pfister et al., 2010; Schuetz et al., 2012).

The main goals of this study were: i) Verify if infrared thermography can be used to visualize preferential flow paths and to identify microrelief elements (e.g. rills, depressions, mounds, ridges) namely in the presence of mulch cover; and ii) try to generate a temperature gradient on the soil surface that permits the estimation of a 3D model of the soil surface microrelief, knowing only a few (at least two)

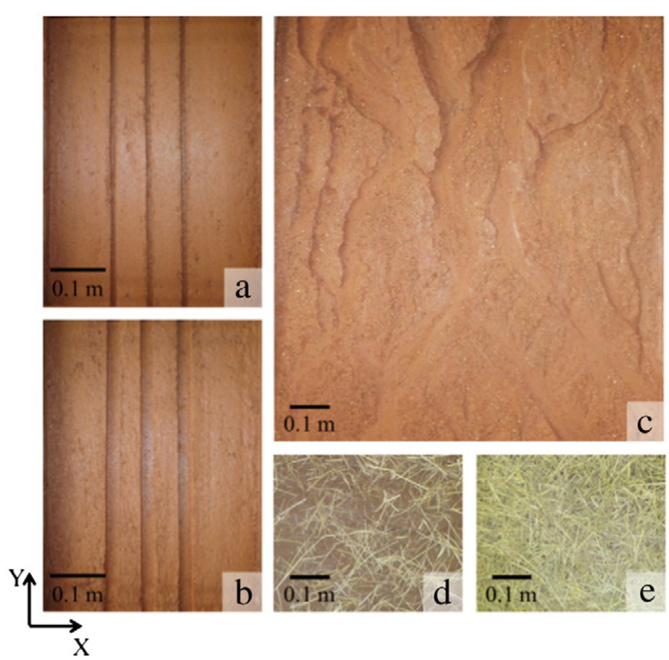

Fig. 2. Photographs of the soil surface of the flumes: a) Small study section with artificially created rills; b) bare soil with microrelief created by water erosion; c) low mulching cover; and d) high mulching cover. X represents the distance along the width of the flumes and Y represents the distance along the length of the flumes.

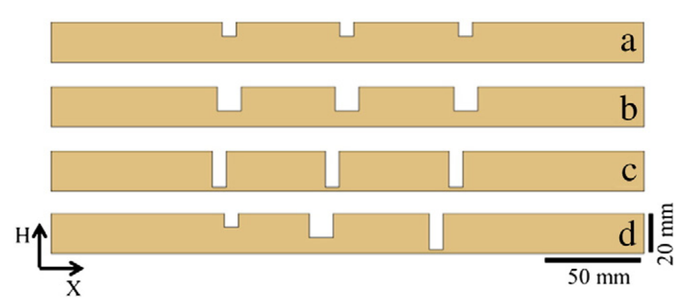

Fig. 3. Soil surface elevation profiles of the scenarios with artificial rills: a) Scenario with three small rills (see Fig. 2a); b) scenario with three large rills (see Fig. 2b); c) scenario with three deep rills; and d) scenario with a combination of three rills with different sizes. X represents the distance along the width of the flume and H represents the soil surface elevation.