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Calibration of manual measurements of rills using Terrestrial Laser Scanning

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ABSTRACT

This article reports the results of a field investigation aimed at comparing and verifying the agreement between two methods measuring rill morphological characteristics at the Masse experimental area. At first, the data obtained both with a manual method (profilometer) and with a Terrestrial Laser Scanner (TLS) were compared. The comparison showed that the manual measurements underestimate the width at the top of the cross sections and the length of the rill segments. Calibration curves were derived for these characteristics and were used to correct the manual data. The comparison between the corrected total length and volume and between the morphological characteristics of the measured rills at Masse showed that the power relationships available in the literature are valid also for the silty-clay soil in Masse.

1. Introduction

The success of any experimental research program relies on selecting the suitable experimental technique and accurate and appropriate measuring methods. In particular the accuracy of the data collection method must be verified both when direct and indirect measurements are performed. In either case, calibration is necessary to verify all the factors affecting the results. Reliable calibration of any experimental device is considered the main step for a successful experimental program.

In soil erosion research, monitoring the processes at different spatial and temporal scales is of outmost importance in order to formulate, calibrate and validate predictive models needed to define the “risk areas” and to quantify this risk. Usually the proper calibration and validation of the models for the area in which they are used make use of soil loss databases and studies carried out on a local scale.

Some experimental investigations (Morgan, 1977; Govers and Poesen, 1988; Rejman and Brodowski, 2005; Yang et al., 2006; Bruno et al., 2008; Liu et al., 2011; Di Stefano et al., 2013) aimed at establishing the contribution of rill and interrill erosion to the total soil erosion suggested that rill and channelized erosion (rill; ephemeral gully, EG; gully, G) is dominant compared to interrill erosion. Consequently when modeling soil erosion the estimate of the channelized component should be stressed. Measurements of rill erosion under field conditions are usually used to quantify the rill volumes and the corresponding weights of the eroded soil (Di Stefano et al., 2014).

The most widely used survey method consists of manual measurements, and has gained widespread acceptance as being a reliable, parsimonious and economical method. The manual methods are typically based on the assessment of cross sectional areas with micro-topographic profilers and of the rill length with a tape or ruler along the channels (McCool et al., 1981; Govers, 1987, 1991; Govers and Poesen, 1988; Auzet et al., 1993; Smith, 1993; Ludwig et al., 1995; Vandaele and Poesen, 1995; Casalí et al., 1999; Bennett et al., 2000; Nachtergaele et al., 2001a,b; De Santisteban et al., 2005; Bruno et al., 2008; Di Stefano and Ferro, 2011; Di Stefano et al., 2012, 2013, 2014; Vinci et al., 2015). Casali et al. (2006) tested different methods to derive the channel volumes based on the direct assessment in the field of the rill cross sectional areas. The analysis of the errors obtained showed that: a) the micro-topographic profiler always provided the most precise measurements; b) it is important to select an adequate cross section; and c) the distance between consecutive cross sections must be less than 5 m to guarantee an error value smaller than 10%.

Moreover, the micro-topographic profilers are frequently handmade, so even though a standardized procedure is used (for example, for measuring rill features each rill has to be divided into segments), the measurement variability could be accentuated by the different profilers used. Recent studies on soil erosion stressed a great degree of unexplained variability of soil loss measurements due to both natural characteristics and measurement errors (Nearing et al., 1999; Bagarello and Ferro, 1998; Nearing, 2000; Todisco et al., 2012).

For these reasons in recent years more accurate and technologically-advanced measurement techniques (such as Terrestrial Laser Scanning, airborne photogrammetry, photogrammetry in general) are also used because they are becoming costless and readily available. These techniques

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enable one to obtain high resolution topography and consequently to produce sub-meter resolution Digital Terrain Models and Digital Surface Models (Tarolli, 2014) over large areas (with a grid size of 10 m) and on a small scale (such as plot scale, with a grid size of a few centimeters). Moreover, these surveying techniques make it possible to quantify the sheet and channelized erosion processes in various measurement conditions: in impervious situations (Pirotti et al., 2012; Tarolli et al., 2012, 2013), in laboratory experiments (Berger et al., 2010), and at the experimental plot scale (Gessesse et al., 2010; Carollo et al., 2012; Wirtz et al., 2012, 2013; Di Stefano et al., 2013; Carollo et al., 2014; Fang et al., 2014; Vinci et al., 2014, 2015).

At the plot scale, Vinci et al. (2015) assessed the capability of Terrestrial Laser Scanning (TLS) to detect and map the rill morphology and then to evaluate the eroded volume. Thus the continuous Triangulated Irregular Network (TIN) model obtained by the TLS survey was used as the reference for the morphological characteristics (length, width, depth and area) of the rill formations.

The use of both manual and automatic measurement techniques for data collection brings about the contemporaneous presence of measurements made by different methods in the Masse soil loss databases. Hence the consistency between the different data types needs to be verified to correct if necessary the manual measurements and make them consistent with automatic measurements (probably more accurate in the quantification of rill volumes).

In this study the Masse experimental station database (Todisco et al., 2012; Vinci et al., 2015) of manual and automatic rill morphological characteristics (length, width, depth and volume) was used to derive the relationships (calibration curves) between the manual measurements and the corresponding values surveyed by Terrestrial Laser Scanning. Later the manual measurements were first corrected using the calibration curves, and then used for testing both the empirical relationship between total rill length and its eroded volume (proposed by Capra et al., 2009 and calibrated by Di Stefano et al., 2013) and the adimensional relationship between the morphological data (Bruno et Di Stefano and Ferro, 2011; Di Stefano et al., 2012, 2013).

2. Materials and methods

2.1. Experimental site and measurement techniques

The Masse experimental station for soil erosion measurements at the plot scale was set up in 2008 by the University of Perugia. The station is located 20 km south of Perugia, in Umbria Region (Central Italy). The area is characterized by a hilly topography, the soil is a Calcaric Cambisol (FAO-ISRIC-ISSS, 1998), and the station includes 10 plots of different widths and lengths: 8 × 22 m (experimental schemes A, B, C, D), 4 × 22 m (experimental schemes E, F), 4 × 11 m (experimental schemes G, H), and 2 × 11 m (experimental schemes I, L). All plots are oriented according to the maximum slope (16%) and were maintained in a cultivated fallow, and rills were obliterated at the end of the erosive event. Rainfall data are measured within the experimental station at 5-min time intervals. The lower side of each plot is delimited by a groove that intercepts the runoff and conveys it to the storage tanks. The mean event plot soil loss A_e ($t \cdot ha^{-1}$) and the total plot runoff are measured following the procedure described in Todisco et al. (2012) and in Bagarello et al. (2013).

In the 2010–2013 period 47 erosive events were recorded, and only three of them yielded rill formations (11 January 2010, 16 May 2011, 11 November 2012). The corresponding total rainfalls P_e were 150.6 mm, 56.4 mm, 217.8 mm and the rainfall erosivity indices R_e, computed according to Wischmeier and Smith (1978), were 175.16, 359.37 and 629.9 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$, respectively.

For these events the manual direct survey of the rills was done using a profilometer, and the statistics of the morphological characteristics surveyed are given in Table 1. In addition, for the 11 November 2012 event, the rill formation survey in one 8 × 22 m plot (experimental scheme C) was done also using Terrestrial Laser Scanning.

2.2. Manual rill surveys and processing

To measure manually the rill characteristics (width, depth, cross section area and length), each rill, r, was suitably segmented in $N_{r,s}$ parts, $s = 1,\ldots, N_{r,s}$, and each segment length, $L^p_{r,s}$, was measured by a metric ruler. Rill cross sections were identified along transverse transects having, as a rule, a 2 m inter-distance, and were surveyed by a profilometer. The pin profilometer consisted of 44 stainless steel pins spaced 5 mm apart (Di Stefano et al., 2012; Vinci et al., 2014, 2015). The pin configuration after the cross section survey was photographed and digitized directly from the pictures to derive the cross section characteristics: the width, $w^p_{r,s}$ (m), measured at the top of the cross section; the maximum scour depth, $H^p_{r,s}$ (m); and the cross section area $A^p_{r,s}$ (m^2). The values of $w^p_{r,s}$, $H^p_{r,s}$ and $A^p_{r,s}$ associated to each rill segment were set equal to the values measured at the upslope cross sections of the rill segment (Table 1). The rill segment volume, $V^p_{r,s}$, was thus calculated using the following relationship:

$$V^P_{r,s} = 0.5\left(A^P_{r,s} + A^P_{r,s+1}\right)L^p_{r,s}. \quad (1)$$

The total rill volume V^p_r (m^3) was calculated as follows:

$$V^P_r = \sum_{s=1}^{N_{r,s}} V^P_{r,s}. \quad (2)$$

Table 1
Morphological characteristics of the rill segments surveyed manually: plot size; experimental scheme; number of rills, n; width at the top, $w^P_{r,s}$(min, max, mean and coefficient of variation expressed in percent, CV); maximum scour depth, $H^P_{r,s}$ (min, max, mean and coefficient of variation expressed in percent, CV); rill segment area, $A^P_{r,s}$ (min, max, mean and coefficient of variation expressed in percent, CV).

Erosive event date	Plot size (m × m)	Experimental scheme	n	$w^P_{r,s}$ (m)				$H^P_{r,s}$ (m)				$A^P_{r,s}$ (m^2)			
				Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)
1/11/2010	8 × 22	B	4	0.015	0.092	0.052	39.9	0.013	0.057	0.036	31.8	0.0008	0.005	0.002	56
		C	2	0.01	0.057	0.036	40.4	0.010	0.047	0.033	40.4	0.0006	0.0027	0.0015	50.6
5/16/2011	4 × 22	E	2	0.009	0.07	0.037	57.84	0.031	0.068	0.047	24.7	0.0013	0.0045	0.0031	38
		F	3	0.019	0.07	0.038	35.94	0.024	0.068	0.047	24.3	0.0009	0.0075	0.0027	55
	4 × 11	H	3	0.019	0.067	0.036	30.41	0.021	0.061	0.042	29	0.0009	0.0048	0.0023	44.7
11/11/2012	8 × 22	C	8	0.05	0.39	0.136	42.8	0.004	0.095	0.076	128.4	0.0008	0.0514	0.0072	104
	4 × 22	E	13	0.045	0.26	0.107	31.3	0.009	0.109	0.056	42.7	0.0005	0.014	0.004	72.6
		F	11	0.025	0.35	0.106	45.3	0.025	0.12	0.063	38.1	0.0007	0.023	0.005	83.6
	4 × 11	G	8	0.037	0.15	0.095	31.1	0.022	0.085	0.052	30.5	0.0012	0.008	0.003	41.7
		H	5	0.065	0.21	0.12	32.5	0.036	0.1	0.07	23.9	0.001	0.014	0.004	71.2
	2 × 11	I	3	0.065	0.15	0.11	28	0.028	0.1	0.05	39.3	0.0018	0.007	0.004	41.6
		L	3	0.065	0.15	0.097	24	0.033	0.07	0.05	24.5	0.0018	0.006	0.003	35.6