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A modified applicative criterion of the physical model concept for evaluating plot soil erosion predictions

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ABSTRACT

In this paper, the physical model concept by Nearing (1998. Catena 32: 15–22) was assessed. Soil loss data collected on plots of different widths (2–8 m), lengths (11–44 m) and steepnesses (14.9–26.0%), equipped in south and central Italy, were used. Differences in width between plots of given length and steepness determined a lower data correlation and more deviation of the fitted regression line from the identity one. A coefficient of determination between measured, *M*, and predicted, *P*, soil losses of 0.77 was representative of the best-case prediction scenario, according to Nearing (1998). The relative differences, $Rdiff = (P - M) / (P + M)$, decreased in absolute value as *M* increased only for erosion rates approximately >1 kg m^{-2}. An alternative applicative criterion of the physical model concept, based on the $|P - M|$ difference, was valid for the entire range of measured soil losses. In conclusion, the physical model should be defined in terms of perfect planimetrical equivalence. The best applicative criterion of the physical model concept may vary with the considered dataset, which practically implies the need to further test this concept with other datasets.

1. Introduction

Using a model for predicting soil loss due to water erosion is useful to predict both the aggressiveness of the phenomenon in an area of interest and the effects of different soil erosion control practices. These predictions have interest for many reasons, including safeguard of the people. For example, many valley towns in Italy are crossed by streams that are frequently covered by roads. In these cases, there is the need to reduce ordinary sediment yield to tolerable levels, so to minimize the risk of obstruction of the stream at its outlet. Obstruction phenomena can favor disastrous flooding during severe rainfall events (e.g., Bagarello et al., 2010b).

The performances of a soil erosion model have to be tested for establishing the expected reliability of the soil loss estimates (Foster and Lane, 1987; Quinton, 1994). The quality of the predictions can be established only if a criterion to discriminate between "acceptable" and "unacceptable" soil loss estimates is available.

Although an erosive event occurring on plots having identical characteristics in terms of soil, morphology, land use and crop management practices yields runoff and soil loss data varying from plot to plot (Bagarello and Ferro, 2004, 2006; Ruttimann et al., 1995; Wendt et al., 1986), a single or a few replicated plot soil loss data are generally collected for a given treatment. The circumstance that similar plots give different soil loss outputs affects the performance evaluation of a soil erosion model. In fact, for a particular condition, the departure between the measurement and the corresponding prediction has to take into account the prediction error, due to the model structure and the input data, and the deviation of the measured sample value from the representative mean value (Nearing, 2000).

According to Nearing (1998), the best possible model to predict soil loss from an area is a physical model of the area which is characterized by a similar soil type, land use, size, shape, slope and climatic inputs. In other words, the physical model obtained by a replicated plot is the best possible, unbiased, real world model. Using event soil loss data for approximately 3000 pairs of replicated plots, Nearing (1998) compared the measured, *M*, soil losses and the predicted, *P*, ones obtained by the physical model represented by the replicated plot. Nearing (1998) obtained a coefficient of determination, R^2, of the linear relationship between *P* and *M* equal to 0.77 and he concluded that an uncalibrated erosion model would not give a better overall result. Nearing (2000) also proposed that a soil erosion prediction has to be considered acceptable if the difference between the prediction and the measurement lies within the population of differences between pairs of measured values. Using a large set of plot soil loss data collected in different U.S. locations, Nearing (2000) also developed empirical relationships to predict the 90% and 95% occurrence intervals of the relative differences, *Rdiff*, between replicated plots as a function of the measured soil loss.

In a previous paper, the soil loss measurements carried out in Sicily, at the Sparacia station, supported the conclusion that a coefficient of determination between measured and predicted soil losses of 0.77 has to be considered as a benchmark or best-case prediction scenario

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(Bagarello and Ferro, 2012). The 95% occurrence interval for the data developed by Nearing (2000) included approximately 88–89% of the data collected at Sparacia. Taking into account that this discrepancy was moderate, i.e. a few percentage units, and considering that a large sample size and a wide variety of conditions were considered in the U.S. study, the conclusion by Nearing (2000) that the developed analysis should be usable for model validation studies in general was considered to be reasonable.

The influence of plot width, w, on the definition of the physical model should be considered. Bagarello and Ferro (2012) assumed that w did not affect the analysis and a single data set was considered for a given event for the 22 m long plots independently of w (2 or 8 m). The reasons of this choice were: i) the plots included in the investigation by Nearing (2000) ranged from 2 to 8 m in width, ii) a recent investigation (Bagarello et al., 2011) showed that soil loss differences between two plot widths were not statistically significant at Sparacia and plot width effects were negligible for the most erosive events, and iii) in plot soil loss models such as the Universal Soil Loss Equation (USLE) and its revised version (Renard et al., 1997; Wischmeier and Smith, 1978), soil loss per unit area is considered to depend on plot length but not on plot width. However, plot width affected measurement of soil loss for the less erosive events, suggesting a more appreciable dependence of the plot response on the local conditions in this last case. We did not find other investigations of the plot width effects on the measured soil loss in the literature. Therefore, establishing these effects with reference to the physical model concept is necessary to include data of appropriate quality in the (P, M) dataset.

Another point to be developed is the possibility to generalize the results by Nearing (2000), which was partially supported by Bagarello and Ferro (2012). Nearing (2000) used a huge dataset but his approach has a strong empirical connotation. For example, Nearing (2000) considered a minimum soil loss of 0.01 kg m^{-2} whereas smaller values were included in the investigation by Bagarello and Ferro (2012). Therefore, extending the investigation to other data and environments is desirable to be sure that the developed analysis is usable for model validation studies in general or to recognize the need or the opportunity to modify the procedure. In other terms, the methodology developed by Nearing (2000) to establish the effect of the severity of the erosive event on the expected differences between predicted and measured soil loss needs testing with data not included in the U.S. database. This test might suggest the opportunity to improve the methodology but such an improvement should be carried out by maintaining the centrality of the physical model concept. To our knowledge, however, no other studies are available which tested the physical model concept.

The general aim of this paper is to test the physical model concept by using soil loss data collected on plots of different lengths, widths and slopes at two experimental stations located in southern and central Italy. The three specific objectives are to: i) establish the plot width effects with reference to the physical model concept; ii) assess the applicability of the existing procedure to test plot scale soil erosion models; and iii) develop an alternative procedure to assess the suitability of an erosion model for soil loss prediction.

2. Materials and methods

Data for this investigation were collected at the "Sparacia" (south Italy) and "Masse" (central Italy) experimental stations for soil loss measurement (Table 1). The characteristics of the two stations were described in detail in other papers (e.g., Bagarello and Ferro, 2004; Bagarello et al., 2011; Todisco et al., 2012) and they were only summarized here for brevity reasons. In particular, the experimental station for soil erosion measurement "Sparacia" of the Department of Agricultural and Forestry Sciences of the Palermo University is located in western Sicily, southern Italy, approximately 100 km south of Palermo. It includes two plots of 8×44 m^2, two plots of 8×33 m^2, six plots of 8×22 m^2, two plots of 2×22 m^2, two plots of 4×11 m^2, and two plots of 2×11 m^2. The oldest plots (four plots of 8×22 m^2) were constructed in 1999, whereas the most recent plots (two plots of 2×22 m^2) were constructed in 2007. All these plots were installed on a 14.9% slope. Two plots of 6×22 m^2 were also realized on a 22.0% slope and other two plots (6×22 m^2) were constructed on a 26.0% slope. The area has a typical Mediterranean semi-arid climate with an average annual rainfall of approximately 700 mm. The soil has a clay texture (clay = 62%, silt = 33% and sand = 5%) and it shows a massive consistency in winter, when it is wet and fully swelled, but it develops a polygonal pattern of surface shrinkage cracks in late spring or early summer as the soil dries. The experimental station for soil erosion measurements "Masse" of the Department of Civil and Environmental Engineering of the Perugia University was established in 2007. It is located 20 km south of Perugia in the Umbria region (central Italy). The station includes ten plots: four plots of 8×22 m^2, two plots of 4×22 m^2, two plots of 4×11 m^2, and two plots of 2×11 m^2. All plots are oriented parallel to a 16% slope. The area has a characteristic Mediterranean climate with an average annual rainfall of 900 mm. The soil has a silty–clay–loam texture (clay = 34%, silt = 59% and sand = 7%). The structure is polyhedral angle and the gravel content is negligible. All considered plots were maintained in a cultivated fallow and rills were obliterated by hand implements at the end of each erosive event.

Events with two or more replicated measurements for a given plot type (length, width and slope steepness) were included in this database and the physical model concept was tested according to Nearing (1998). Two data points were obtained from the soil loss data collected, for a given event, at the two available plots of given geometric characteristics. For the first data point, one value (A) of the pair was chosen to serve as the measured, M, value of erosion and the other (B) was considered to

Table 1
General characteristics of the sampled plots and erosive events.

Station	Plot width and length (m)	Number of plots	Slope steepness (%)	Sampling period	Erosive events	N	A_e (kg m^{-2})			$N_{<0.01}$ (%)	$N_{>1}$ (%)
							Min	Max	Mean		
Sparacia	2 × 11	2	14.9	09/2004–10/2011	21	42	0.0048	11.31	0.80	11.9	21.4
	4 × 11	2	14.9	09/2004–10/2011	22	44	0.0027	7.28	0.92	9.1	20.5
	2 × 22	2	14.9	09/2007–10/2011	11	22	0.0099	3.42	0.66	4.5	22.7
	8 × 22	6	14.9	11/1999–01/2012	52	235	0.00029	21.70	1.05	19.6	22.6
	6 × 22	2	22.0	09/2007–03/2012	19	38	0.011	8.35	1.48	0	44.7
	6 × 22	2	26.0	09/2007–03/2012	19	38	0.014	7.84	2.07	0	65.8
	8 × 33	2	14.9	01/2002–01/2012	39	78	0.00024	6.68	0.86	15.4	25.6
	8 × 44	2	14.9	09/2004–01/2012	23	46	0.00012	5.62	0.80	28.3	15.2
Masse	2 × 11	2	16.0	11/2008–12/2011	23	46	0.0065	3.48	0.59	2.2	19.6
	4 × 11	2	16.0	03/2008–05/2012	37	74	0.0024	2.33	0.32	12.2	8.1
	4 × 22	2	16.0	03/2008–05/2012	35	70	0.00075	1.17	0.13	35.7	1.4
	8 × 22	4	16.0	02/2008–05/2012	43	86	0.00040	0.96	0.06	58.1	0

A_e = event plot soil loss per unit area; N = sample size, i.e. number of individual plot soil loss data; $N_{<0.01}$ = percentage of A_e values smaller than 0.01 kg m^{-2}; $N_{>1}$ = percentage of A_e values greater than 1 kg m^{-2}.