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Using plot soil loss distribution for soil conservation design

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ABSTRACT

Soil conservation design is generally based on the estimation of average annual soil loss but it should be developed taking into account storms of a given return period. However, use of frequency analysis in soil erosion studies is relatively limited. In this paper, an investigation on statistical distribution of soil loss measurements was firstly carried out using a relatively high number of simultaneously operating plots of different lengths, λ (11, 22, 33 and 44 m) at the experimental station of Sparacia (southern Italy). Using a simple normalization technique, the analysis showed that the probability distribution of the normalized soil loss is independent of both the scale length λ and the temporal scale, which are completely represented by the mean soil loss calculated for a given event using all replicated data collected in plots having the same length. Then, a comparison between the frequency distribution of soil loss and rainfall erosivity index of the USLE was carried out. An estimating criterion of the annual soil loss of a given return period was also developed. By this criterion, the frequency distribution of the rainfall erosivity factor can be used to design soil conservation practices.

1. Introduction

Soil conservation design is generally based on the estimation of average annual soil loss because the most applied soil erosion prediction models were not designed to estimate erosion at event temporal scale (Baffaut et al., 1998). As an example, the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) and its revised version (RUSLE, Renard et al., 1997) were developed to predict long-term average erosion amounts from cultivated fields for use in conservation planning. Taking into account that a large proportion of total soil erosion over a long time period is due to few large storms (Larson et al., 1997), soil conservation practices or strategies based on mean annual soil loss values can provide adequate erosion control in most years but unacceptable soil loss can occur for the largest erosion-producing events. Therefore, conservation strategies should be developed taking into account large storms rather than average weather conditions.

From an engineering point of view, the erosion storm has to be defined to design a soil conservation system or to establish an erosion control strategy. If an historical sequence of soil loss values, having a sufficient sample size, is available then a frequency analysis is developed and the soil erosion variable having a given return period can be estimated (Baffaut et al., 1998; Mannaerts and Gabriels, 2000). According to Larson et al. (1997), conservation systems should be designed for limiting soil loss (namely, tolerance) to the value corresponding to a return period variable from 10 to 20 years.

Notwithstanding that the concept of using long-term hydrological data for a probabilistic representation of the hydrological phenomena is well known, and is currently employed for rainfall–runoff (Alexander et al., 1969; Alila, 2000; Chow, 1954; Ferro and Bagarello, 1996; Ferro and Porto, 1999) and flood studies (Cunnanne, 1985; Cannarozzo et al., 1995; Ferro, 2006; Rossi et al., 1984; Ward and Elliot, 1995), the use of frequency analysis in soil erosion studies is relatively limited (Bagarello et al., 2010; Baffaut et al., 1998; Edwards and Owens, 1991; Hession et al., 1996; Istok and Boersma, 1986; Larson et al., 1997; Mannaerts and Gabriels, 2000; Zuzel et al., 1993).

In a previous investigation, Bagarello et al. (2010) demonstrated that the scale effect due to the measurement carried out with different microplot and plot lengths, λ (λ = 0.25, 0.4, 11, 22, 33 and 44 m) is completely represented by the mean value. In other words, the probability distribution of the normalized soil loss, defined as the ratio between an individual plot soil loss value and the mean of the soil losses measured for a given event in all replicated plots having the same length, is independent of both λ and the temporal scale, which are completely represented by the mean soil loss value. Bagarello et al. (2010) also showed that the frequency distribution of the normalized soil loss obtained by all available measurements and the one corresponding to the annual maximum values were overlapping and not significantly different. Therefore, the parameters of the probability distribution of the annual values of maximum event soil loss and the quantiles of given return period, *T*, can be estimated using all available data.

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In this paper, an investigation on statistical distribution of soil loss and rainfall erosivity data was carried out using simultaneously operating plots of different lengths (λ = 11, 22, 33 and 44 m) at the experimental station of Sparacia (southern Italy). In particular, length effects on the normalized soil loss distribution were further tested. Then, a comparison between the frequency distributions of soil loss and rainfall erosivity index was carried out. Finally, an estimating criterion of the annual soil loss of a given return period, usable to design soil conservation practices, was developed.

2. Experimental area and measurement technique

The experimental station for soil erosion measurement "Sparacia" of the Agricultural Faculty of the Palermo University is located in western Sicily, Southern Italy, approximately 100 km south of Palermo. It includes two plots of 44×8 m^2 (I and L in Fig. 1), two plots of 33×8 m^2 (G and H), six plots of 22×8 m^2 (A to F), two plots of 22×2 m^2 (Q and R), two plots of 11×4 m^2 (M and N), two plots of 11×2 m^2 (O and P), and several microplots. The oldest plots (four plots of 22×8 m^2) were constructed in 1999, whereas the most recent plots (two plots of 22×2 m^2 and some microplots) have been constructed in 2007. All considered plots and microplots were installed on a 14.9% slope. The area has a typical Mediterranean semi-arid climate with an average annual rainfall of approximately 700 mm. The dry period of the year can extend for seven months (April–October). The soil is a Vertic Haploxerept (Soil Survey Staff, 2006) with a clay texture (62% clay, 33% silt, and 5% sand). The soil 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 gravel content is negligible. The depth of the Ap horizon is of approximately 0.30 m. Rainfall data are measured by a recording rain-gauge located in the experimental area (Fig. 1) at 1-min time intervals.

Runoff and associated sediments from each plot are intercepted by a gutter placed along the lower end of the plot, and then they are collected into a storage system consisting of three tanks of known geometric characteristics, each having a capacity of approximately 1 m^3, that are arranged in series at the base of each plot. A single tank is installed at the base of the 11-m-long plots and two tanks are used for the 22×2 m^2 plots. Total runoff and soil loss are measured after each erosive event (i.e., an event producing measurable runoff) or, occasionally, after a series of events if they are separated by a very short time interval. At first, the water level in the tank is measured. Then, the suspension (water + sediments) is thoroughly mixed and samples are collected at different depths along a vertical by ten sampling taps to determine the suspended sediment concentration profile. A mean measured concentration value is calculated by integrating the measured profile and this mean value is then transformed into the actual concentration of sediments stored in the tank using the calibration curve of the storage system (Bagarello and Ferro, 1998; Bagarello et al., 2004). By this curve, the risk of measuring soil loss values lower than the actual ones is appreciably reduced. The plots were generally maintained in a cultivated fallow and rills were obliterated at the end of each erosive event. Using data from bare plots is particularly important because most soil is removed for agricultural land (e.g. Pimentel et al., 1995), that is exposed to the direct action of the erosive agents for part of the year. For example, sloped, wheat fields are common in several semi-arid Mediterranean areas. In these areas, the soil surface is not protected by the crop for a relatively long period of the year (three or four months), and rainfall erosivity can be particularly noticeable during this period (D'Asaro and Santoro, 1983).

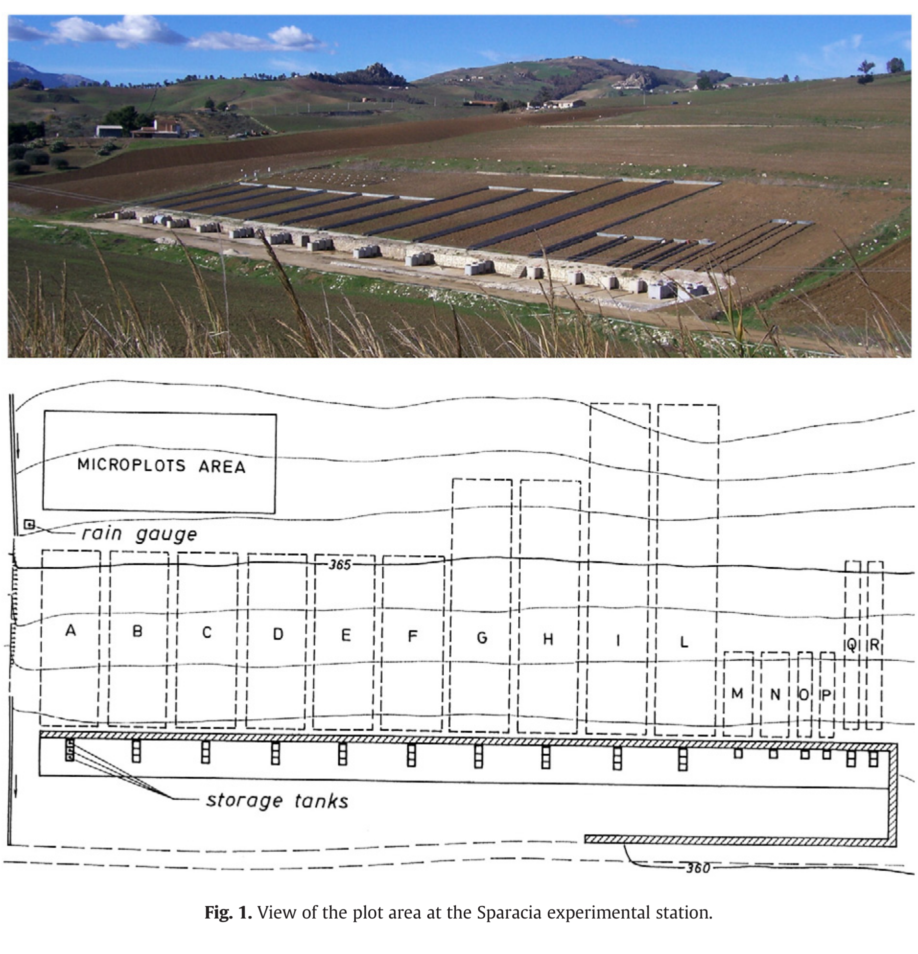

Fig. 1. View of the plot area at the Sparacia experimental station.