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Morphological characteristics of ephemeral gullies in Sicily, south Italy

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Abstract: Ephemeral gullies (EGs) are channels of different sizes refilled by tillage equipment normally used on farms. In this paper, the data-set collected from 1995 to 2007 in a wheat-cultivated area in Raddusa (Sicily, Italy), having a surface of almost 80 ha, were used to analyze the morphological characteristics of EGs. The measurements show an high temporal variability in EG characteristics. The EG measurements and the rill erosion measurements carried out in 15 plots located in the experimental "Sparacia" area (Sicily), demonstrated that a morphological similarity condition exists between rills and ephemeral gullies. The occurrence of step-pool structures in an EG occurring in the observation period in the same place allows to conclude that, in the considered environment, an ephemeral channel, such an EG, similarly to a stream, tends to reach a step-pool morphology as the structure that maximises its stability.

Keywords: ephemeral gully erosion, erosion measurements, morphological characteristics, rill erosion, Sicily

Introduction

Ephemeral gullies (EGs) are channels of different sizes, mainly (but not only) located in swales, refilled by tillage equipment normally used on farms (SSS of America 2001, Poesen et al. 2003, Casali et al. 2006, Capra & Scicolone 2002). Ephemeral gully erosion is a severe problem in many cultivated fields: crops are washed out in the areas where EGs develop and are submerged by the sediment at their lower end, and filling operations reduce the long-term productivity of the farmland (Woodward 1999). Furthermore, EGs constitute effective links for transferring runoff and sediment from uplands to valley bottoms (Valentin et al. 2005) and rapidly evolve in permanent gullies that contribute to denudation processes, may generate new badlands, and aggravate off-site effects of water erosion (Capra et al. 1994, Capra & Scicolone 1996, Torri et al. 2000, Poesen et al. 2003, Della Seta et al. 2007). Field-based studies evidenced annual soil losses due to EG erosion ranging between 2 and 100 $m^3 ha^{-1} yr^{-1}$ and constituing from 10 to more than 100% of the total soil loss in agricultural watersheds (e.g.: Vandaele 1993, Poesen et al. 1996a, 2003, Casalí et al. 1999, 2006, Cerdan et al. 2002, Martínez-Casasnovas et al. 2002, Poesen et al. 2003, Valcárcel et al. 2003, Cheng et al. 2006, Capra et al. 2009a).

No systematic compilation of the different EG types and morphological characteristics in a wide range of environments has been made, in spite of the analysis of the EG hydraulic geometry, that could contribute to the understanding of the processes acting on their development. Casalí et al. (1999), based on field observations, described three main types of EGs: classical EG, formed by concentrated runoff flowing within the same field where runoff started; drainage EG, created by concentrated flows draining areas upstream from the field; and discontinuity EG, commonly found in places where management practices create a sudden change in slope, such as field boundaries adjacent to roads.

Measurements carried out from 1995 to 2007 in a wheat-cultivated area in Sicily (Italy) represent one of the longest field data series on EG erosion. The aim of this paper is the analysis of morphological characteristics of EGs in the studied area and its comparison with the morphological characteristics of others erosion channel types as rills and streams.

Methods

Study area

The area surveyed (surface area equal to 80 ha) is located near Raddusa (province of Catania), in central Sicily, Italy, and belongs to a national network of experimental catchments for erosion studies. The altitude ranges between 305 and 483 m above sea level and the mean slope is 16.4%. The dominant soil association is Vertic Xerocrepts, which is very common in Sicily (Fierotti 1997). The main textural classes are Silt Clay Loam and Clay (sand 33–39%, silt 22–38%, clay 29–45%); the gravel content is negligible; the bulk density ranges between 1,140 and 1,170 kg m^{-3}; the organic matter content of the soil ranges from 0.98 to 1.13%. The soil profile does not show delimited horizons until a depth of 1.2 m. The climate is Mediterranean with annual rainfall height of about 500 mm (mean 1971–2007), and standard deviation of about 205 mm. More than 80% of the rainfall is concentrated in the October–May period, named here hydrological year. The main crop in the area is durum wheat. Some active EGs occur in the observed area during the rainy season. They frequently occur in the same places during the next rainy season. EGs are erased by filling with soil from areas adjacent to the channel using ordinary tillage equipment during tillage operations from July to October, before sowing (Capra et al. 2009b).

In the wheat areas, the farmers do not move soil or level the EGs from sowing to harvest, and the surveyed EGs resulting from all erosive events in the hydrological year.

Field measurements of ephemeral gully erosion

The term EG system is used here to indicate the whole of the main branch and the interconnected tributaries of an EG. The area has been monitored for EG development on a yearly scale since 1995 (Capra & Scicolone 2002). The EG measurements were made at the end of May each year. A Post Processing Differential GPS was used to measure the spatial co-ordinates of points located about every 5 metres of channel in the longitudinal direction. Cross sections were measured about every 20 m of channel, or whenever any change in the EG section, or the presence of tributaries, was observed (see Capra et al. 2009b for details).

Morphological similarity between ephemeral gullies and rills and between ephemeral gullies and streams

As it is known, rills are considered ephemeral structures, having an intermittent plan network and an irregular cross-section shape. Some authors use a threshold cross sectional area or depth to distinguish rills from EGs (Poesen et al. 1996b, 2003).

The morphological similarity between rills and EGs was tested using the rill measurements carried out in 15 plots located in the experimental "Sparacia" area (province of Palermo), Sicily (Bagarello & Ferro 2004, Bruno et al. 2008). The dimensional analysis and the theory of self-similarity (Barenblatt 1987, Capra et al. 2009c) were applied.

Finally, the characteristics (e.g. height, distance, mean slope) of some step-pool structures observed at event scale and detected in most recent years in an EG occurring in the same place, rainy season after rainy season, were measured. Steps and pools are characteristic bedforms that dominate the channel morphology of steep mountain streams. The step-pool morphology features of EG was compared to the one typical stream reaches using the theory proposed by Abrahams et al. (1995).

Results

Ephemeral gully characteristics

Ephemeral gully formation occurred eight years out of twelve, with a return period of 1.5 years (Capra et al. 2009b). Averaging the results over the 12 years, then including the years with zero EG erosion, the total number, length and eroded volume in the examined area were 15 EGs yr^{-1}, 1,696 m yr^{-1} and 278 m^3 yr^{-1} respectively. The corresponding values averaged over the wheat area were 0.19 EGs ha^{-1} yr^{-1}, 21 m ha^{-1} yr^{-1} and 3.5 m^3 ha^{-1} yr^{-1} (about 0.4 kg m^{-2} yr^{-1}) respectively. The measurements showed an high temporal variability in EG characteristics which was generally in agreement with the rainfall characteristics (Capra et al. 2009b) and with the field surveys in other environments (Poesen et al. 2003, Valentin et al. 2005).

Both classical, drainage and discontinuity EGs (Casalì et al. 1999) were observed in the field survey. The number of different EG types was almost equal in the years when a high EG number was observed, whereas classical and drainage EGs dominated in the years with lower precipitation and lower number of active EGs.

Table 1 shows the main characteristics of the measured EGs. The mean length of the active EG systems, main branches and tributaries were equals to 98, 113 and 33 m respectively (Table 1); 90% of

Table 1. Synthesis of the main characteristics of ephemeral gullies in the rainy seasons from 1995–1996 to 2006–2007 in the study area

	Tributaries[a] (n)	Length (m)				Mean width (m)			Mean depth (m)	Mean cross section (m^2)	Eroded volume (m^3)
		main EGs	tributaries[a] total[a]	tributaries[a] mean[b]	systems	upper	lower	medium			
Min	0.00	5.83	5.41	5.41	5.83	0.36	0.13	0.26	0.08	0.001	0.06
Max	7.00	369.06	476.80	95.36	782.32	1.09	0.51	0.77	0.31	2.177	284.70
Mean	0.36	97.93	78.61	32.99	112.81	0.65	0.28	0.47	0.19	0.198	18.50
Standard deviation[c]	0.33	68.62	105.29	18.21	101.25	0.33[c]	0.14[c]	0.22[c]	0.14[c]	0.343[c]	37.46

[a]for EG systems, [b]for tributaries, [c]of the mean values

the EG systems showed a length shorter than 245 m. The EGs observed in the study area had rectangular or trapezoidal cross-sections. The mean width of the upper, lower and medium sections of the EG systems were 0.65, 0.28 and 0.47 m respectively; ca. 90% of the measured sections showed a mean width smaller than 0.75 m. The mean depth of EG systems was 0.19 m; ca. 95% of the measured sections had a depth smaller than 0.5 m, which represents the maximum depth of the tillage operations in the area, so this arable layer is easier to erode.

A limited number of cross sections located at the bottom of the valley reached depths greater than 2 m, evolving into classic gullies. Although channels of such depth are not usually considered ephemeral, farmers in the area continue to fill these EGs when the deeper segments are shorter.

The mean area of the cross sections was 0.2 m^2; 90% of the measured sections showed an area lesser than 0.46 m^2. The EGs observed in Sicily generally showed mean cross sections higher than EGs observed by Casalí et al. (1999) in Navarra, which cross sections ranged between 0.04 and 0.09 m^2, with a cross-section area of the largest gullies quasi almost equal to 0.16 m^2. Opposite, there were smaller than those measured in the Inner-Mongolian Plateau, which mean depth ranged from 0.50 to 0.76 m, and the width was 0.7–3.0 m (Cheng et al. 2006).

The observation of Casalí et al. (1999), establishing that the greatest sections occurred in the central part of classical ephemeral gullies and gradually decreased toward the upstream and down-stream ends, does not apply to Sicilian EGs. In fact cross sections of Sicilian EGs generally increased in a downstream direction (see Fig. 1 as example for some EGs).

In different years, both EG systems comprising a main branch alone and those with a main branch and one or more tributaries were active. The mean number of active tributaries per EG in the study area ranged from 0 to seven, with a mean number of 0.36 (Table 1). The tributaries were generally shorter than the main channels (Table 1).

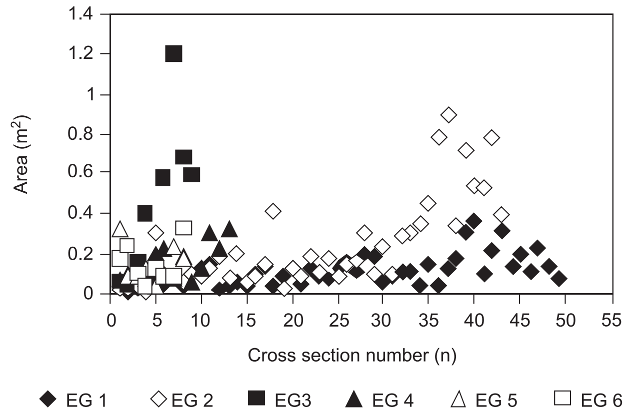

Fig. 1. Cross section areas in the downstream direction

The formation of tributaries was observed mainly in the years when the precipitation were heavier and higher erosive and represents the last phases of the EG formation and development (Capra et al. 2009b). The tributaries only appeared when the length of the main EG reached the maximum allowed by the drainage area and length of the catchment (Capra et al. 2009b).

Morphological similarity between rills and ephemeral gullies and between ephemeral gullies and streams

Using the rill and the EG data described, the morphological similarity between rill and ephemeral gully was tested. Firstly the applicability of the power relationship (Eq. 1) between total channel length (L, m) and total eroded volume (V, m^3) proposed by several authors (Nachtergaele et al. 2001; Capra et al. 2005) to Sicilian rill measurements was tested:

$$V = a_s L^{b_s} \quad (1)$$

The analysis allowed to establish that Eq. 1 can be applied for both rill and EG measurements using the same exponent b_s = 1.1956 and a different scale factor a_s which was equal to 0.0423 for the EG systems and 0.0039 for the rills.

The analysis also showed that the functional relationship (Eq. 2) between the eroded volume and the morphometric characteristics of the erosion channels developed by Bruno et al. (2008) was valid for both rills and EGs:

$$\frac{V}{L^3} = F\left(\frac{wH}{L^2}\right) \tag{2}$$

Applying the incomplete self-similarity theory (Barenblatt 1987; Capra et al. 2009c) the following power relationship was obtained:

$$\frac{V}{L^3} = a_r\left(\frac{wH}{L^2}\right)^{n_r} \tag{3}$$

Figures 2a, b, c and d show that Eq. 3 fits well for rills and for both EG main channels and tributaries, measured in both humid or dry soil conditions, with a_r= 0.5072 and n_r= 0.9222 (Capra et al. 2009c). In other words, a morphological similarity between rills and EGs was confirmed, and, opposite to V-L relationship, a scale-factor depending on channel type (rill or EG) was not necessary.

Conventional bedform variables characterised the individual step-pools (Abrahams et al. 1995, Chin 1999, Ferro 2006) observed in the EG measured at event scale: wavelength (Ls) represents the distance between two successive trough points pool to pool, height (H) is measured by the perpendicular distance between the crest and an imaginary line connecting the troughs of the step-pool unit, and S is the slope of the bed channel.

According to Abrahams et al. (1995), the Eq. 4 can be applied to a stream that tends to evolve to a step-pool structure that maximises their stability:

$$\frac{H}{L_S} = cS \tag{4}$$

where c is a coefficient ranging between almost 1.5 (Abrahams et al. 1995; Lenzi & D'Agostino 2000; Lenzi 2001) to 2.5 (Zimmermann & Church 2001).

Eleven and 14 step-pools were clearly visible in the EG measured in May 2008 and November 2009, re-

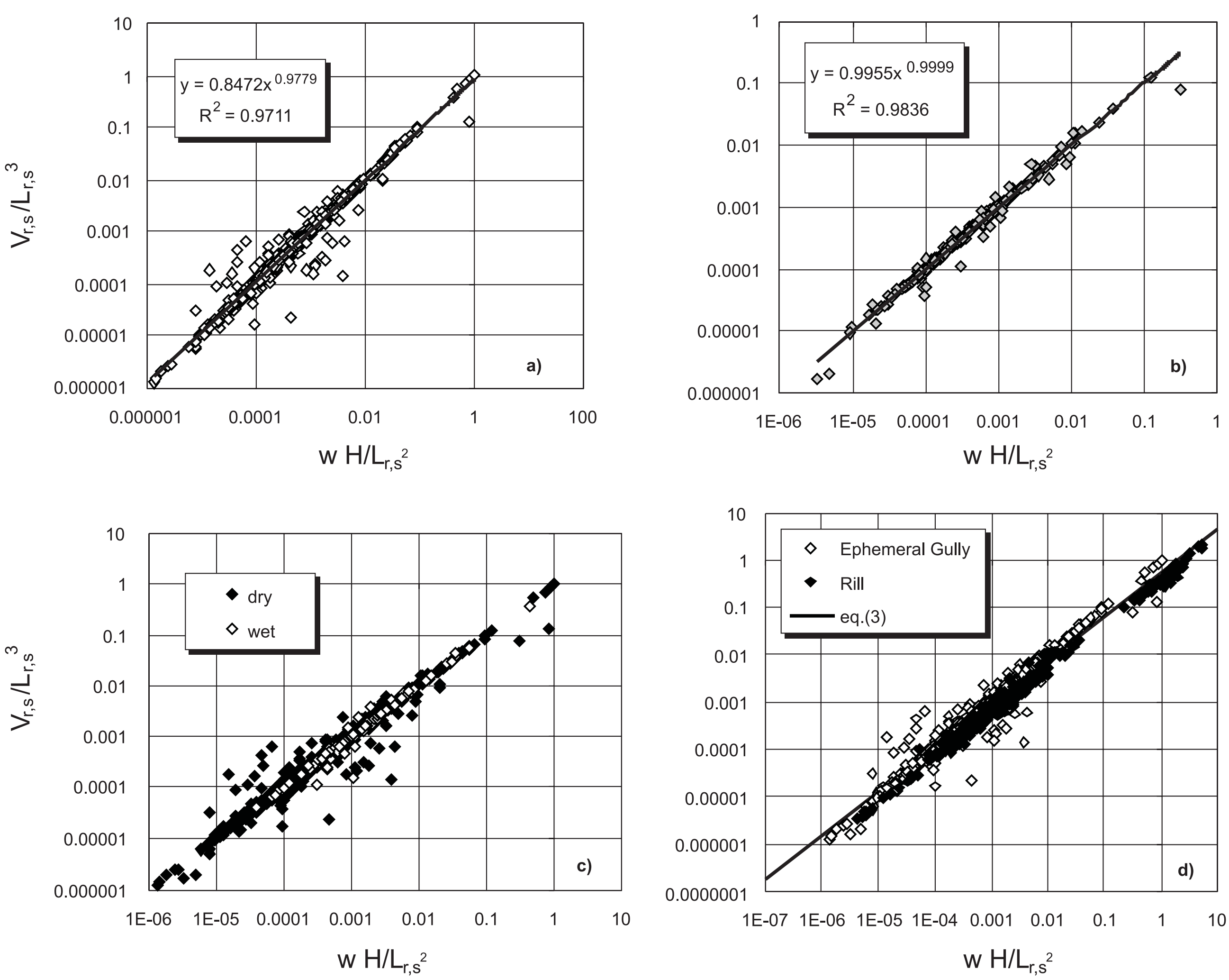

Fig. 2. Comparison between Eq. 3 and the measurements carried out in EG systems (main branches (a), tributaries (b), in different water content conditions (c), comparison with rills (d))

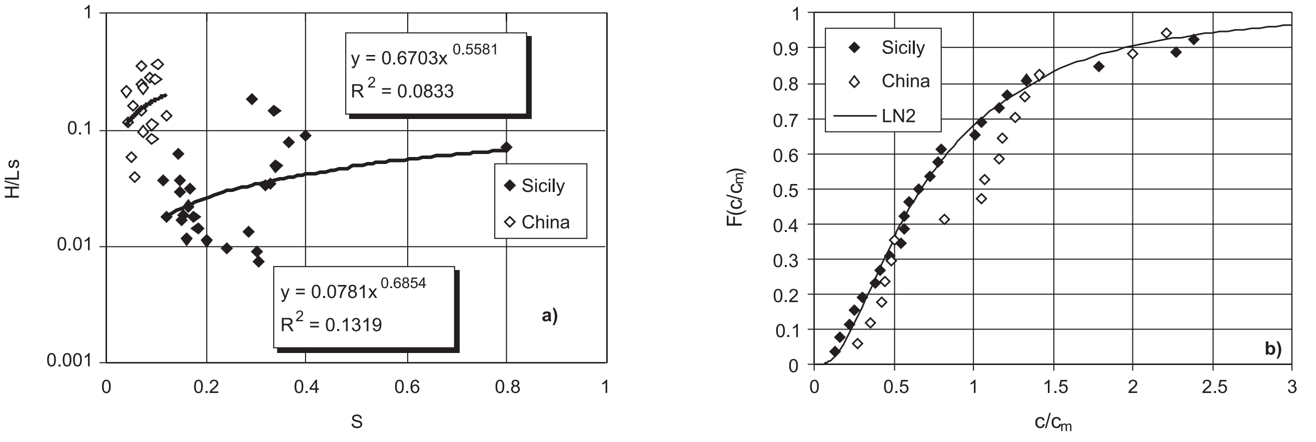

Fig. 3. Relationship between the ratio H/L_s and the slope S (a) and frequency distribution of the ratio c/c_m (b)

spectively. The mean values of H, L_s and S were 0.19 m, 8.32 m and 25%, respectively; the mean value of c was equal to 0.19, lesser than the values characterising the streams. Figure 3a shows a great dispersion for both c values related to sicilian and chinese (Cheng et al. 2006) data. Figure 3b shows the frequency distribution of the ratio c/c_m (where c_m is the mean value of c) for both the sicilian and chinese data. Both the data-set seem to belong to the same group, but the logarithm distribution fits well sicilian data.

Conclusions

Ephemeral gully erosion is not an infrequent event in cultivated wheat zones in Sicily (Italy). From 1995 to 2007 EG formation was observed eight years out of twelve in the experimental catchment of Raddusa. Ephemeral gully characteristics presented great interannual variability, in agreement with the rainfall characteristics. Similarly to others Mediterranean areas, both classical, drainage and discontinuity EGs were observed in the field survey. In different measurement years, both EG systems comprising a single branch and those with a main branch and one or more tributaries were active. The width and depth of tributaries were lower than those of the main branches. The EGs observed in the study area had rectangular or trapezoidal cross-sections. Almost 90% of the measured sections showed a mean width lesser than 0.75 m; ca. 95% of the measured sections had a depth lesser than 0.5 m, which represents the maximum depth of the tillage operations in the area.

The study demonstrated that a morphological similarity condition exists between rills and ephemeral gullies. In other words, the evolution of the erosion process determines an imprinted channel which is geometrically similar at different (rill, ephemeral gully) scale.

Finally, the occurrence of step-pool structures in an EG occurring in the same place from 1995 to 2007 allows to conclude that, in the considered environment, an ephemeral channel, such an EG, similarly to a stream, tends to reach a step-pool morphology as the structure that maximises its stability.

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