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Effects of rows arrangement, soil management, and rainfall characteristics on water and soil losses in Italian sloping vineyards

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Abstract

Erosional processes are highly affected by seasonal climatic fluctuations and soil management practices. Controlled grass cover is one of the most used soil conservation practices adopted in temperate climates, even if the protective effect of grass cover may decrease according to seasonal pattern. This technique is effective and, thus, widely adopted in the inter-rows of orchards such as olives, citrus or vineyards. This study reports the erosive events recorded in two different rain-fed hillslope vineyards, with different rows orientation, located in the Monferrato region, NW Italy. The study is addressed at compare the effects of different inter-row managements and rainfall characteristics on runoff and soil loss in hillslope vineyards (average slope from 15% to 35%). Rainfall, runoff and erosion variables were monitored in hydraulically bounded vineyard plots, where the inter-rows were managed with tillage and grass cover. Seventy-two erosive events were recorded in the period 1992-1996, in two vineyard plots with rows along the contour lines and eighty-six erosive events were recorded in two plots with rows up and down the slope from 2000 to 2014 (158 erosive events and four plots in total). Events were classified according to rainfall characteristics as “long-lasting”, “intense” and “normal”. In plots with rows along the contour lines, “intense” events were responsible for the highest mean soil loss in tilled plots (0.7 Mg ha^{-1}) with very high erosion rates (12.3 Mg ha^{-1}) observed during a single storm. In plots with rows up and down the slope the highest erosion rates, 21.2 and 3.4 Mg ha^{-1}, were recorded during fall “long-lasting” events, in the tilled and grass cover plots, respectively. The grass cover proved to be effective in decreasing runoff and soil losses during most of the events (at least 68% and 61% of the occurrences, respectively), reducing soil losses especially during summer storms when most of “intense” events occur. Furthermore, the results show the fundamental role of contour-slope row orientation in reducing runoff and soil losses, disregarding the inter-rows soil management that is adopted.

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1. INTRODUCTION

In 2016, vineyards covered over 7.5 million ha (OIV, 2017) representing about 0.5% of the agricultural area at a global scale. However, in 2016, wine market moved around 29 billion of dollars in the world (OIV, 2017), bringing their products at the top of the agricultural market. In Europe, vineyards cover 3.3 million ha and Italy, with 690.000 ha, is ranked at third position, after Spain and France (OIV, 2017). Piedmont (NW Italy) has a vineyard surface of 43.500 ha, nearly totally devoted to wine production, including 17 PGI (Protected Geographical Indication) and 42 PDO (Protected Designation of Origin) wines (Regione Piemonte, 2017a, 2017b). In 2014 *The Vineyard Landscape of Piedmont: Langhe, Roero and Monferrato* was recognized as UNESCO World Heritage Site for the outstanding landscapes and the importance of vinegrowing and winemaking in the Region (UNESCO, 2014). Vineyards are mostly located in the southern part of the region and more than 88% of the Piedmont vineyard surface is on hilly areas while over 8% is on mountain areas (Regione Piemonte, 2017c). At the same time more than 40% of the hilly areas of the Piedmont region are characterized by soils with erosion rates higher than 15 t ha^{-1} yr^{-1} (IPLA, 2009).

In the last decade, much attention has been paid to environmental impacts of agricultural activities, especially as regards soil degradation. The Soil Thematic Strategy from the European Union (EU) in 2006 (CEC, 2006a, 2006b) identified soil erosion as one of the major threats that affect European agricultural soils. Soil erosion processes in vineyards have been studied across Europe in order to assess runoff and soil water erosion rates in this agricultural system (Rodrigo-Comino and Cerdà, 2018;; Martínez-Casasnovas et al., 2016;; Novara et al., 2015; Corti et al., 2011), using different methodologies and obtaining erosion rates ranging from 0.02 t ha^{-1} yr^{-1} measured by runoff plots over a 2-year period in Spain by Ruiz-Colmenero et al. (2011) to 15.7 t ha^{-1} yr^{-1}, estimated for a 44-years period using the technique of botanical benchmark in a mountain vineyard in North-Italy (Biddoccu et al., 2017b). Panagos et al. (2015b) estimated soil loss in Europe for the reference year 2010 by the application of a modified version of the Revised Universal Soil Loss Equation model (RUSLE2015): the mean soil loss rate in the European Union's erosion-prone lands (agricultural, forests and semi-natural areas) was found to be 2.46 t ha^{-1} yr^{-1}, resulting in a total soil loss of 970 Mt annually. Permanent crops, including vineyards, showed the highest soil erosion rate among agricultural land uses (9.47 t ha^{-1} yr^{-1}), accounting for 10% of the total soil losses in the European Union. Furthermore, measured data (Maetens et al., 2012) showed that in the Mediterranean region runoff coefficients higher than 9% are related to vineyard land use.

Under the same land use, climate, topography, soil texture and soil management are recognized as the factors primarily affecting soil erosion (Biddoccu et al., 2016; Prosdocimi et al., 2016a; Novara et al., 2011; Cerdan et al., 2010). With regard to climate, many studies have been carried out to investigate the effects of rainfall characteristics on runoff and soil erosion (Biddoccu et al., 2017a; Gómez et al., 2014; Taguas et al., 2010). Many experiments focused on soil erosion in vineyards are located in hillslope areas, with a slope gradient up to 35% (Rodrigo-Comino et al., 2017a, 2017b), as this is the typical landscape hosting vineyards in the European area. Specifically, a large number of studies investigates the effect on runoff and erosive processes of different soil managements and cover solutions in vineyards (Gómez, 2017; Prosdocimi et al., 2016b;; Novara et al., 2011;).

Several studies highlighted that the use of grass cover in the inter-rows is one of the most common and effective soil management practice adopted to reduce runoff and soil erosion in vineyards (Ferreira et al., 2018; Morvan et al., 2014; Gómez et al., 2011;), improving also other ecosystem services (Garcia et al., 2018; Winter et al., 2018;; Montanaro et al., 2017;). Moreover, grass cover in vineyards has been comprised in the most relevant European policies for soil conservation, including the Standards of Good Agricultural and Environmental Condition (GAEC), established by Council Regulation No. 73/2009 (CEC, 2009). Indeed, under European Common Agricultural Policy (CAP), GAEC standards impose a set of requirements aiming at preventing soil erosion such as: (i) minimal soil cover maintenance, (ii) minimum land management reflecting site specific conditions to soil loss, and (iii) maintenance of soil organic matter level. Grass covering measures have been supported also at local level by Rural Development Programmes (RDPs) that are drawn up by Member States and regions addressing common CAP EU priorities that include prevention of soil erosion and improvement of soil management. With regard to Italy and Piedmont region, the measures envisaged during the 2007-2013 RDP for soil erosion prevention were essentially based on the grass covering of orchards and vineyards areas and involved more than 13,000 ha (15.4 % of Piedmont's agricultural area utilized for orchards and vineyards) (IPLA, 2016).

Management of the plantations, and in particular the orientation of the rows in relation to the slope lines of the field, is an additional measure able to limit the erosion phenomena. In Piedmont, both orientation of the vine rows, up and down the slope and along contour lines, are adopted, depending on the slope angle, to support field mechanization and increase the land productive potential (Corti et al., 2011), because of the influence of orientation on physiological behavior of vines (Hunter et al., 2016). Nevertheless, in many studies, erosion rates are considered without pay attention to the orientation of the vine rows (Prosdocimi et al., 2016a).

Thus, this study aims at comparing the results of two experiments recording runoff and soil losses in two rainfed hillslope vineyards located in the same region, with similar soil management and inclination, but different vine rows orientation. In particular, the objectives of the study are: i) to compare the effects of grass cover with tillage in the vines inter-rows in terms of runoff and soil loss in hillslope vineyards with different row orientation; and ii) to evaluate the influence of event rainfall characteristics in determining the hydrological and erosive response of the vineyards with different row orientation.

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2. MATERIALS AND METHODS

2.1 Experimental sites

Since 1980, the Institute for Agricultural and Earthmoving Machines (IMAMOTER) of the National Research Council (CNR) of Italy has been carrying out studies on the effect of soil management on runoff and erosion in sloping vineyard. The results presented in this paper refer to soil erosion monitoring activity carried out by IMAMOTER in Piedmont, in two locations on hilly area (Figure 1): the Vezzolano Experimental Farm (45°08’N, 7°96’E, 426 m a.s.l., located in the municipality of Albugnano), and the Tenuta Cannona Experimental Vine and Wine Center of Agrion Foundation (44°40’N, 8°37’E, 296 m a.s.l., located in the municipality of Carpeneto). The data have been collected in the two sites over the period 1992-1996 and 2000-2014, respectively. As typical in the Monferrato area, vineyards are arranged with rows along contour lines (“girapoggio”) and up and down the slope (“rittochino”). In the Albugnano area, vines are traditionally arranged along the contour lines while in the Carpeneto area a significant part, approximately 1/4, of the vineyards in sloping conditions are arranged with rows up and down the slope.

2.1.1 Experimental Farm of Vezzolano

This farm is located in northern part of the Monferrato area, best known as “Basso Monferrato”. The area is characterized by dry summer and cold winter with snowfall events, corresponding to a transitional climate between pre-alpine and sublitoranean (ARPA, 2017). In the period 1962-2004, the mean annual precipitation was 846 mm, mainly concentrated in May, October and November. while the driest month was July. In the same period the mean annual air temperature was 11.8°C. Soil texture is silt loam (24% clay), and the soil is classified as *Typic Udorthent* (Nigrelli, 1998; Soil Survey Staff, 2010), derived from Miocene silty marls of the Tertiary Piedmontese Basin (Tropeano, 1984).

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The runoff and soil erosion data were collected from 1992 to 1996 in two plots, each one part of a vineyard grown along contour lines on a hillslope with south/south-east aspect and average slope of 15%. The monitored plots consisted in two 5200 m^2 portions of the vineyard and include rows at 2.75 m across the hillslope (originally, 15-35% gradient) arranged with slight longitudinal slope (2-10%), terraced at the head of every four rows, to mitigate the hillslope to 12-20% (Figure 1b-c). Every 20 rows a wider inter-row (linking levelling road) with uphill counterslope collects and diverts to the head-rows the drainage water. Inter-rows were managed according the most common local practices with i) autumn ploughing and summer hoeing (named, from here on out, conventional tillage, CT); ii) grass cover mowed and chopped three times per years (named, from here on out, controlled grass cover, GC).

In the observation period rainfall was recorded with a mechanical weather station. Pluviographs were used to obtain precipitation characteristics and sub-hourly rainfall intensity for erosive rainfall events.

2.1.2 Experimental Area of Tenuta Cannona

The farm is located in the southern part of the Monferrato area, known as “Alto Monferrato” (Figure 1). The Cannona vineyards lie on Pleistocenic fluvial terraces in the Tertiary Piedmont Basin, including highly altered gravel, sand and silty clay deposits, with red alteration products (Servizio Geologico d’Italia, 1969). The soils have a clay to clay-loam texture. The climate is sublitoranean. According to the nearest long period weather station (Ovada, 187 m asl) the average annual precipitation over the period 1951–1990 is 965 mm, mainly concentrated in Autumn (October and November) and Spring (March) while the driest month over the period was July (Biancotti et al., 1998). . The mean annual air temperature measured at the experimental site in the period 2000–2014 was 14.5°C while the average annual precipitation was 905 mm.

This study refers to measurements carried out from 2000 to 2014 in two vineyard plots, which are part of a larger vineyard, planted in 1999 on a hillslope with south-east aspect and average 15% slope.

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Each plot is 1221 m^2 (74 m long and 16.5 m wide) and includes 7 vine rows aligned along the slope, where the vines are spaced 1.0 m along the row and 2.75 m between the rows (Figure 1d-e-f). The soil in the two plots has been managed with two different techniques corresponding to the local practices: i) cultivation with chisel to a depth of about 0.25 m (named, from here on out, conventional tillage, CT) and ii) spontaneous grass controlled with mulcher during the year (named, from here on out, controlled grass cover, GC). The mulcher mows and chips the grass and the residues are left on the soil surface. Soil tillage (in CT) and grass mulching (in GC) were usually carried out twice a year, one in spring and one autumn. In autumn 2011, the inter-rows of the GC plot were tilled and a grass mixture was sown (*Lolium perenne L.* 20%, *Festuca rubra L.* 60%, *Poa nemoralis L.* 15%, *Poa trivialis L.* 5%.), to renew the grass cover. Weeds under the rows of the two plots were controlled with Glyphosate application in spring, on the surface 0.6 m across the vine row. Most of the farming operations in the vineyard were carried out using iron track-lying or wheeled tractors, with intensification from spring to the grape harvest time, in fall.

Rainfall data for the experiment period were obtained from two agro-meteorological stations, both placed at about 200 m from the plots. Data about precipitations (along with air temperature and air relative humidity) have been continuously recorded by means of mechanical instruments. Since 2003, data have been also measured and recorded by electro-mechanical station that is included in the Piedmont Agro-meteorological Regional Network, that provides daily and hourly data. The latter, along with pluviographs, were used in order to obtain precipitation characteristics and sub-hourly rainfall intensity for erosive rainfall events.

2.2 Runoff and soil erosion monitoring

Each monitored plot was hydraulically bounded. Runoff and transported sediments from each plots were collected by a channel surrounding the plot (Figure 1c-f) and connected to a sedimentation trap and, then, to a tipping bucket device to measure the discharge of runoff (Figure 2). A portion of the runoff-sediment mixture was sampled for each tip. The tipping bucket devices were calibrated to measure runoff with 0.1 mm resolution. In addition, only for the Cannona plots, since 2011, hourly measurements of the runoff volumes were obtained from electro-magnetic counters. After each erosive event, a 1.5 L sample of runoff-sediment mixture was collected. Sediments deposited along drains and in the sedimentation traps were also collected and weighed after being dried. To obtain the sediment yield from each erosive event, sediment concentration was multiplied by the runoff volume and added to the weight of deposited sediments.

2.3 Data analysis

Data collected by monitoring stations were processed and some derived parameters were calculated. All rainfall events recorded from June 1992 to December 1996 in the Vezzolano site and from April 2000 to December 2014 in the Tenuta Cannona site were checked and only events with a runoff higher than 300 L ha^{-1} and sediment concentration higher than 0.01 g L^{-1} in at least one of the plots were selected and considered in the study. Following this criteria, 72 and 86 erosive events wereconsidered for the site of Vezzolano and 86 for the site of Tenuta Cannona, respectively. For the latter experimental site, within the considered period, soil-loss events produced by snowfall melting (n=9) were not included in the analysis, because the different relationships between precipitation characteristics of such events and the generation of runoff and erosion processes (Renard et al., 1997). Selected erosive rainfall events were described with the following variables and dimensions: (i) rainfall depth (RF_depth, mm); (ii) rainfall duration (RF_duration, hrs); (iii) maximum rainfall intensity over a 30-min period (Imax30, mm h^{-1}); (iv) mean rainfall intensity (Imed, mm h^{-1}), (v) rainfall erosivity (EI30, MJ mm ha^{-1} h^{-1}), (vi) runoff depth (RO, mm); (vii) runoff coefficient (RC, %) evaluated as RO depth divided by RF_deph; (viii) mean suspended sediment concentration as the total mass of transported suspended sediment per runoff volume (SSC, g L^{-1}) and (ix) total soil loss (SL, kg ha^{-1}). Maximum rainfall intensity was extracted from the pluviograph records on paper sheets

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evaluating minimum ranges of 30 minutes. Rainfall event erosivity (Renard et al., 1997) was computed by means of RIST (Rainfall Intensity Summarization Tool) (ARS-USDA, 2015). Considered events have been classified according to rainfall event characteristics into three main types: “long-lasting” (RF_duration > 50hrs), “intense” (RF_Imax30> 16mm/h) and “normal” (other events). According to explored literature, there are no univocal references to classify rainfall events (Sansom and Thomson, 1992; Gaál *et al*., 2014; Dolšak *et al*. 2016, Panagos *et al*., 2015a; Lin *et al*., 2016). As suggested by the World Meteorological Organization in “Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events” (2016) a common method of ascertaining thresholds is based on selecting the tail of distributions for precipitation, and statistical partitions such as by quartiles or percentiles of the distribution provide a mean for evaluating extremes. Therefore, in this study a statistical approach was adopted, in order to define “long-lasting” and “intense” events: based on available datasets of rainfall characteristics for both sites, the 3rd quartile was calculated for rainfall duration (RF_duration) and rainfall maximum intensity (RF_Imax30) distributions. Thus the values corresponding to the 3rd quartile (RF_duration > 50 hrs and RF_Imax30 > 16 mm h^{-1}) were adopted as thresholds for rainfall events classification.

Variables at event scale were averaged and summarized for each experimental site separately, so that the overall effect of the two management treatments (CT and GC) could be determined. Moreover, data were checked for normality using the Kolmogorov–Smirnov test and since normality test failed, statistical differences in average values between both treatments were checked using a Wilcoxon Signed Ranks Test. Moreover, values of runoff (RO), soil loss (SL) and suspended sediment concentration (SSC) were compared performing ANOVA among the three types of event (“long-lasting”, “intense” and “normal”) and between the two soil treatments (CT and GC). The two-way interaction between treatment and event type was included, as well (Wang et al., 2017). The Tukey HSD method was applied at 95% confidence level for multiple comparisons. Pearson correlation matrix and stepwise multiple linear regression were used to illustrate the correlations among RO, SSC, SL and rainfall characteristics. Finally, Mann-Whitney test was used to compare RO, SSC, SL within the same treatment between the two sites, namely between row orientation along contour lines and up and down the slope. Statistical analyses were computed using SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSIONS

3.1 Description of the erosive rainfall events

At the Vezzolano experimental site, a total of 72 erosion-generating events occurred between 1992 and 1996: 20 “intense”, 13 “long-lasting” and 39 “normal” events. Table 1 reports the mean characteristics of selected events for both experimental sites. The mean values of rainfall depth (RF_depth) at event scale were 41.9 mm (n=72), “long-lasting” events were characterized by the highest mean amount of rainfall per event (77.6 mm), and this value was two times higher compared to “normal” (35.6 mm) and “intense” (31.1 mm) events. Mean duration of events ranged from 6.9 hours (“intense events”) to 72.3 hours (“long-lasting” events). Maximum rainfall intensities over a 30-min period (RF_Imax30) ranged from 42.9 mm h^{-1} (“intense” events) to 5.8 mm h^{-1} (“long-lasting” events). Overall mean erosivity of rainfall events (EI30) was 109.1 MJ mm ha^{-1} h^{-1}, “intense” (143.7 MJ mm ha^{-1} h^{-1}) and “normal” (110.8 MJ mm ha^{-1} h^{-1}) events proved on average a higher erosivity compared to “long-lasting” events (50.8 MJ mm ha^{-1} h^{-1}).

Among the 86 erosive events that occurred in the Tenuta Cannona between the years 2000-2014, 25 have been classified as “intense”, 19 as “long–lasting” and 42 as “normal”. The mean RF_depth per erosion-generating event was 65.5 mm (n=86), mean duration per event was 32.2 hours, mean RF_Imax30 was 14.7 (n=73) and mean EI30 was 127.3 MJ mm ha^{-1} h^{-1}. “Long-lasting” events resulted in highest mean rainfall depth (111.6 mm) and duration (74.9 h) while “intense” events resulted in highest maximum rainfall intensities over a 30-min and highest erosivity (Table 1).

Even though the two monitoring experiments were carried out in the same region, the rainfall characteristics of the erosive events show some differences, with mean annual precipitation higher in the Tenuta Cannona area than in Vezzolano site. Monitoring refers to different periods, however studies on climate indicators in Italy did not highlight any changes in rainfall patterns in the last decades (Desiato et al., 2017). Mean rainfall depth at event scale was higher in the Cannona experiment for all type of precipitation events (Table 1). Referring to other rainfall characteristics, mean value of RF_Imax30 was higher in the Vezzolano site (except for "long-lasting" events) and mean rainfall intensity was generally higher for erosive rainfall events recorded at Cannona. Finally, rainfall erosivity associated to the erosive events was higher in the Cannona experiment, except for "normal" rainfall events. The overall average values of mean and maximum rainfall intensities and rainfall erosivity were in the range of those obtained at event scale in studies (at least 3 years of observations) in the Mediterranean area (Taguas et al., 2010; Corti et al., 2011; Raclot at al., 2009), namely in the intervals 3.59 – 9.3 and 7 - 26.72 mm h^{-1} for RF_Imed and RF_Imax30, respectively. Also similar high coefficients of variations were recorded by Gómez et al. (2014) over 5 years of observations in Spain, being the variability at event scale notably larger than the one observed at annual scale.

3.2 Effect of soil management and type of rainfall event on runoff, soil sediment concentration and soil erosion

Results related to mean values in terms of runoff and soil losses in the two experimental sites are summarized in Table 2. Among the mean values calculated over the 72 events recorded in Vezzolano, the runoff and the soil losses in GC were significantly lower than in CT. In the same site, in 68% and 61% of the rainfall events, the runoff and the soil losses, respectively, were lower in GC than in CT (Table A.1). The difference between treatments was statistically significant ($p<0.05$) when compared within the type of events: mean values of RO and SL during "intense" events in GC were 55% and

79% lower than in CT. For "normal" events, only differences in RO resulted statistically significant (-14%) between CT and GC. In terms of SSC, no significant differences between treatments were found.

Comparing values of runoff and soil losses of the 86 events recorded in the Tenuta Cannona experimental site, for 86% and 92% of the rainfall events, the runoff and the soil losses, respectively, were lower in GC than in CT (Table A.2). Considering the totality of erosive events, differences between treatments resulted statistically significant for all the considered variables (Table 2). Similar results were observed examining the events by their type. Though "long-lasting" events in CT resulted in the highest RO (111.63 mm) compared to other types of events, the larger statically significant difference between treatments in terms of RO was observed for mean values of "normal" events: 50.37 mm in CT and 4.22 mm in GC. The highest soil loss at event scale was observed in CT during "intense" events (2432.08 kg ha^{-1}), in this case, mean soil loss per event resulted more than eight times higher than mean values in GC (289.64 kg ha^{-1}).

Figure 3 shows the frequency distributions of event rainfall and runoff depth (Fig. 3a), rainfall erosivity and soil losses (Fig. 3b), for the two sites. The variables rainfall erosivity, runoff and soil losses present a skewed distribution especially in the Vezzolano site, CT treatment (skewness coefficient indicated in the Figures), with many more observations of low magnitude. For these three variables few events presented high, or very high, values, especially for runoff and soil losses, being the scale of x axis different between the two sites. In the dataset from Vezzolano experimental site, the five largest rainfall events represented 17% of the rainfall during 5 years of observations, whilst the five highest records represented 94% of the erosivity, 47% and 48% of the total runoff and 95% and 94% of the total sediment yield, from the CT and GC plot, respectively. In the Tenuta Cannona site, while the five largest rainfall events accounted for 20% of the rainfall during 15 years of observations, the five highest records represented 42% of the erosivity, 34% and 40% of the total runoff, 59% and 54% of the total sediment yield, obtained in the CT and GC plot, respectively. Similar behavior was observed at catchment scale (0.91 ha) in tilled vineyards by Raclot et al. (2009) in France, where 3 events out of 18 were responsible for 46% of the total runoff and 80% of the soil erosion measured in the vineyard fields and in a 6.1 ha olive catchment in Spain, where Taguas et al. (2010) observed that 3 events produced 93% and 85% of the annual runoff in two different years of observation.

The highest variability in results obtained at Vezzolano is due to the very high runoff and soil erosion values that were observed during some storms, primarily the one that occurred on 27-28/08/1993 (EV27, Table A.1). That intense event was characterized by exceptionally high rainfall intensity (RF_Imax30 = 148.8 mm h^{-1}) and resulted in runoff coefficient of 27.1% and 9.6%, and in 12.3 t ha^{-1} and 2.2 t ha^{-1} of soil losses in the CT and GC plots, respectively. This event was preceded by a less intense storm (on 24/08/1993) that caused nearly 0.93 t ha^{-1} of soil losses from the tilled plot. Another summer storm that occurred on 22/08/1992 (EV07, Table A.1) with 100 mm h^{-1} and 30-min maximum rainfall intensity resulted in very high soil losses in both the plots, CT and GC. The cited events occurred in summer, with bare soil exposed to rainfall and erosion in the CT plot, that were tilled in July, and relatively sparse grass cover in GC plot. In the Tenuta Cannona experimental site RO and SL were much higher in both treatments than in the Vezzolano site (Figure 4), with GC resulting in lower average values for all types of events and with significant reduction in soil losses for any type of event, excepted “long-lasting” ones. Highest average RC and SL were related to “intense” storms and to “long-lasting” events in CT and GC, respectively. Highest soil losses (exceeding 20 t ha^{-1}) were recorded in the CT plot during a “normal” event with also high intensity rainfall (RF_depth = 255.0 mm, RF_duration = 75 h, RF_Imax30 = 19.6 mm h^{-1}), that occurred on 18-19/11/2002 (EC22, Table A.2), and during an “intense” storm (RF_depth = 63.4 mm, RF_I30 = 76.2 mm h^{-1}) that occurred on 06/08/2002 a week after a summer tillage operation (EC17, Table A.2). On the other and, highest soil losses in GC (over 3 t ha^{-1}) were obtained during a “normal” event occurred on 14-15/09/2006 (EC41) and during a “long-lasting” event (EC61, 21/11-1/12/2009).

Other authors observed very high soil erosion in tilled vineyards in Mediterranean countries during single rainfall events, ranging from 7.9 to 207 t ha^{-1}, that were measured in Madrid (Marques et al., 2010) in a vineyard lying on 14.0% slope (up-and-down similar to the Cannona vineyard), and in Catalonia (Ramos & Martínez-Casasnovas, 2004), respectively. The latter exceptionally high sediment yield was produced by a 215-mm storm (with a maximum 30-min rainfall intensity that reached 170 mm h^{-1}) in a vineyard, where the vines were planted with rows perpendicular to the maximum slope gradient (average slope 8.9%), interrupted every 8 rows by a hillside ditch or broadbase terrace, and that caused rill and gully erosion across the vineyard. Results of the present study confirms that, in vineyards, very high soil losses and runoff rates occur in single extreme rainfall events, especially in cases where the soil is bare or poorly protected by cover after tillage or grass mulching, as already observed in other tree crops (Martínez-Hernández et al., 2017; Rodrigo-Comino et al., 2017c; Taguas et al., 2015), and that such few events are responsible of most part of soil erosion, disregarding the soil management and row-orientation. The present study shows that the grass cover was effective in reducing soil losses during “intense” events, with more than 80% of SL reduction on the most erosive events. Great effectiveness in reducing soil losses during the most erosive events was also observed by Marques et al. (2010) and Novara et al. (2011) that measured 97% reduction of soil losses in vineyard plots managed with grass cover (*Brachypodium* spp. and a mixture of *Trifolium subterraneum L., Festuca Rubra L., and Festuca ovina L.*, respectively) with respect to tilled plots during a high erosive event. Marques et al. (2010) highlighted also how the difference in mean sediment yields collected by tilled and grass covered plot was remarkable in case of extreme events (25 times higher) with respect to the effectiveness during low-intensity rainfall events (about 5 times higher), as was observed in both sites in this study (Table 2). Nevertheless, in the Vezzolano site, the effect of grass cover significantly reduced runoff and soil losses (up to 90% of reduction) during "normal" events, even if difference was not statistically significant. Only during "long-lasting" events, RO and SL resulted slightly higher in GC than in CT. The results from the Tenuta Cannona experimental site showed how GC was very effective in reducing runoff and soil losses in up-and-down oriented vineyards, especially during "intense" events, with a reduction of erosive protection during "long-lasting events", that typically occurs in the region in late autumn and winter (Biddoccu et al., 2014; Biddoccu et al., 2016). The mean values (Table 2), show that the effect of grass cover in reducing runoff and soil erosion was evident in both sites, resulting in a significant reduction of average runoff (-31% and -87%) and soil losses (-80% and -78%) relative to CT in the Vezzolano and Tenuta Cannona sites, respectively. These evidences are in-line with several studies in vineyards. In an 8-years field study in Tuscany (Italy), Napoli et al. (2017) found out that, compared to harrowed inter-rows, grass cover reduced significantly the average yearly RO (by about 11.7%) and SL (up to 46%), in particular during copious and intense rainfalls. In Blavet et al. (2009) soil losses and runoff were higher in chemically weeded vine plots while in grassed vines RO, SSC and SL were reduced respectively by 37.5%, 14% and 47%. Even higher protective effect was observed in Germany, where Kirchhoff et al. (2017) made a comparison between conventional and organic soil management practices and observed that total RO, SSC and SL in the organic vineyards (with protective grass cover in the inter-rows) reached a reduction of respectively 87%, 68% and 96% respect to conventional management. Similarly, Ruiz-Colmenero et al. 2011 reported high rates of erosion for tilling while permanent cover (*Brachypodium spp.*) offered the best protection against erosion reducing yearly RO up to 84% and SL up to 94%. Moreover, in Novara et al. (2011) soil erosion rates were significantly reduced, up to 74.94%, by cover crops compared to soil tillage. Positive effects of grass cover on soil protection are reported in other tree crops: Gómez et al. (2009) found lower soil losses in grass covered plots (72% lower) compared to tilled ones in olive groves; Keesstra et al.

(2016) found 65%-93% reduction of total average RO and 96-97% reduction of total average SL in apricot orchards plots with vegetation compared to tilled or treated with herbicide ones.

Moreover, results of the 2-way ANOVA performed to assess the interaction between inter-row surface cover and event type revealed that the degree of GC protective effect varied according to the type of the event and was particularly significant in relation to rows disposition. Indeed, in the Vezzolano experimental site, where erosive magnitude is mitigated by disposition along the contour lines, there is no interaction effect between inter-row cover and type of event even though the type of event itself, in particular "intense" events have a significant impact on SSC. On the opposite, in the Tenuta Cannona experimental site, where generally higher rates of runoff and soil loss were observed, the type of event, the inter-row management, and the interactions of the two factors have a significant effect upon all the considered variables. "Long-lasting" events resulted statistically different from other types of event only in terms of RO while "intense" events resulted statistically different as regards SSC and SL.

Also looking at the profile plots (Figure 4), the lines related to CT rise steeper compared to GC meaning that especially in case of storms or intense events, the type of management can contribute to limit runoff and soil losses and particularly in case of "extreme" events, grass covering can significantly reduce the erosion. Even though no previous research has provided sufficient information to quantify the interaction effect between grass covering and the typology of rainfall event, many former studies recognize the role of vegetation cover in reducing water erosion even under extreme simulated rainfalls or heavy storms (Li and Fang, 2016; Lieskovský and Kenderessy, 2014; Durán Zuazo & Rodríguez Pleguezuelo, 2009; Nunes et al., 2009; Nearing et al., 2005; González-Hidalgo et al., 2004).

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3.3 Relationships between rainfall characteristics and runoff and soil erosion effects

The results of Pearson correlation analysis and multiple linear regression revealed the complexity of the response of the plots considering different types of events. As expected, in Vezzolano site, the correlation matrix (Table 3) indicates that, considering the totality of events, runoff, soil sediment concentration and soil loss are positively associated with rainfall maximum intensity (RF_Imax30) for both treatments (correlation significant at level 0.01). Within “intense” events, statistically significant correlation was identified also between erosion variables and the RF_depth in CT and in GC. In GC, RO and SSC were also highly correlated with rainfall erosivity. Within “normal” events, the highest correlations were found between RO and RF_depth and between SSC and RF_Imed in CT, whereas in GC high correlation between SSC and RF_Imax30 was found. Finally, in line with the results of ANOVA, within “long-lasting” events there is generally a weak correlation among investigated indices.

Otherwise, in the Tenuta Cannona site, RO generally demonstrate for both inter-row managements, a stronger correlation with the RF_depth, the RF_duration and the EI30. The same correlation with rainfall characteristics is maintained when considering only “intense” events in CT and GC and “normal” events in GC (Table 3). SSC was moderately correlated with RF_duration and RF_Imed, while a higher correlation (R = 0.514) was observed in CT with RF_Imax30. Higher correlations were observed between SSC and RF_depth, RF_Imax30, RF_Imed and EI30 considering effects of “long-lasting” events in CT, and between SSC and RF_Imed and EI30 considering effects of “normal” events in GC. SL in CT was highly correlated with RF_depth, RF_Imax30, RF_Imed and EI30 considering all 86 events and “long-lasting” events. For the “intense” events, SL was correlated only with RF_Imax30 while for the “normal” events with RF_Imed and EI30. SL in GC correlated with EI30 for all types of events and with rainfall depth for all events and the “normal” events.

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After a preliminary analysis, correlations among different runoff and sediment yield variables were further valuated using the stepwise multiple linear regression models (Table 4). In line with relationships disclosed by the Pearson correlations, all the models referred to Vezzolano site, ensuing the stepwise procedure, included primarily the rainfall maximum intensity (RF_Imax30) that resulted significant in predicting runoff, soil sediment concentration and soil loss in both inter-row treatments. The same relationship between maximum rainfall intensity, runoff and erosion variables highlighted in the present research was already observed by previous studies. In Raclot et al. (2009), total suspended sediment yield was quite well correlated with maximum rainfall intensity at the field scale, even though higher correlation coefficients were observed for maximum rainfall intensity over a 5-min period ($R = 0.859$) than for maximum rainfall over a 30-min period ($R = 0.686$). Prosdocimi et al (2016), in reviewing a dataset of erosion rates and soil loss measurements derived from 34 studies on Mediterranean vineyards, confirmed a significant and positive relationship between erosion rate and mean rainfall intensity for both runoff simulation and runoff plot methods, and between soil loss and maximum rainfall intensity for runoff plot method. In Italian hilly vineyard, results by Napoli et al. (2017) indicated that EI30 was the variable that better correlated with soil losses, expressing from 41.1% to 61.4% and of total variability of regression models. In Taguas et al. (2015) on olive orchards, the maximum rainfall intensity in 30 minutes showed the greatest correlation coefficients with the runoff (0.80, $p<0.05$), runoff coefficient (0.80, $p<0.05$) and sediment load (0.80, $p<0.05$), while in contrast, the rainfall depth showed very poor correlations.

Nevertheless, in the Vezzolano site the rainfall depth (RF_depth) was considered as a second variable in predicting RO in both CT ($R^2= 0.533$) and GC ($R^2= 0.232$) and in predicting soil loss in GC ($R^2= 0.625$) while in runoff and soil loss models for the Tenuta Cannona site, there was a high correlation with rainfall depth (RF_depth) that resulted a significant predictor especially for runoff in GC ($R^2= 0.703$). The role played by RF_depth as a predictor of RO and SL has been observed in vineyard also by Ferreira et al. (2018) and in olive orchard by Gómez et al. (2014). In this latter study, in all the sediment losses models at event scale there was a high correlation with rainfall depth, duration and only moderately with rainfall intensity. The same authors associated this fact to the dominance of erosive processes such as rill and gully erosion, where the runoff energy, related to rainfall depth, plays a major role. Furthermore, in another study carried out in the period 2013-2014 in the same vineyard Biddoccu et al. (2017a) found how the main runoff and erosive events, especially in the GC, were related to the saturation-excess mechanism, which was observed particularly in late autumn and in long-duration winter precipitation events, usually associated with high RF_depth.

Rainfall maximum intensity was included in the model predicting SSC in CT and as a second variable in predicting SL, although the regression equations result moderate in terms of determination coefficient (R^2). According to statistical results the rainfall erosivity is not a good predictor of runoff and soil loss rates in any model in both sites. Gómez et al. (2014) reported the same pattern in a grassed olive orchard, where higher correlation has been found between sediment yield and rainfall depth than that between sediment yield and rainfall erosivity.

3.4 Effect of row disposition on runoff and soil erosion

The differences between mean values of RO and SL measured in the two soil managements were statistically significant in the vineyard, that is the one with rows are aligned along contour lines, for the “intense” rainfall events while only RO was significantly different for the “normal” events. In the Tenuta Cannona plots, that have rows up and down the slope, differences in RO, SSC and SL were significant also considering separately the “intense” and the “normal” rainfall events (for the “long-lasting” events only RO was significatively different) (Table 2 and Fig.5). The highest average values for RO, SSC and SL in the Vezzolano site were obtained from the “intense” events in both treatments, and the same was observed in the Tenuta Cannona site for the CT plot, whereas in GC the highest RO and SL were measured during the “long-lasting” precipitation events. Furthermore, the “intense”

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events had significant impact on SSC of both treatments in the Vezzolano site, whilst, in the Tenuta Cannona plots, a more complex response in terms of runoff and soil erosion variables to different type of events was observed depending on the soil management (Figure 4). As discussed above, the primary role of "intense" rainfall events in producing runoff and, particularly, soil erosion in sloping vineyards that was found in this experiment was demonstrated by several other studies, but most of them refers to vineyard with rows aligned with the maximum slope. The highest soil losses were recorded in the two Vezzolano experimental plots during the storm occurred on 27-28/8/1993 (Imax30 = 148 mm h^{-1}), shows that during extraordinary rainfall events the vineyard can experience soil losses that exceeds by one or more orders of magnitude those usually observed in the same field, especially if managed with tillage, as already observed by Marques et al. 2010, due to the formation of rills and ephemeral gullies, also in terraced vineyards (Ramos & Martínez-Casasnovas, 2004). However, even considering the contribution of exceptional events, and though the average slope of the plots is similar, mean values of soil losses were significantly higher in the Tenuta Cannona experiment (average values from 139 to 2462 kg ha^{-1}) than in the Vezzolano vineyard (mean values ranging from 0.83 to 736 kg ha^{-1}), for both CT and GC treatments, with mean reduction of 81% and 83%, respectively. Ramos (2016) simulated with WEPP the effect of implementing drainage terraces, without contour planting, in tilled vineyards in the Anoia region (Spain) to reduce soil erosion, where annual soil losses ranged between 6.8 Mg ha^{-1} in 2012 and about 10 Mg ha^{-1} in 2011: the author obtained predicted reduction ranging between 31 and 59%, with an average of 45%. In the same region, simulations showed that the introduction of drainage terraces reduced the soil losses up to 20% in a small basin, whose main land use is vine cultivation (Ramos et al., 2015). The predicted soil losses reductions were smaller than the one measured in our study, however higher reductions can be reached when contour planting is associated with terracing. Indeed, considering the introduction of contour farming in a 107 km^2 watershed in Kenya, where agriculture represents the 40% of land use,

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Mwangi et al. (2015) obtained reduction of sediment load by 24% and of surface runoff by 12%. In the Vezzolano vineyard the average amount of runoff that was obtained for the two soil treatments was, as well, very low (mean values lower than 1 mm for any type of event), if compared with values measured in the Tenuta Cannona vineyards (average values from 4.22 mm to 111.63 mm), resulting in mean runoff coefficients reduced by 89% and 85% for CT and GC, respectively (Figure 5). Differences between the two sites in SSC resulted significant only in CT treatment (with 40% reduction at Vezzolano), whereas the mean sediment concentration in GC at Vezzolano resulted only slightly lower than at Cannona, considering all events, and higher for “intense” events. Despite the higher sediment concentration, during “intense” events mean soil losses were reduced by contour planting (-48%), thanks to the runoff decrease (-79%) in comparison to up-and-down rows arrangements.

In this study the different response to rainfall events in the two experiments could be partially ascribed to differences in the rainfall characteristics between the two locations, as discussed above. Nevertheless, the results show that the main factor, driving the dissimilar response in the paired plots with the same soil management, is clearly the vine rows orientation: the vineyard with rows arranged along contour slopes experienced runoff coefficient lower than 4% and average event soil losses much lower than 1 t ha^{-1} in the period of observation, even in the worst combination (“intense” event on CT plot). The positive effect in soil conservation of contouring is well known and, conversely, the adoption of up-and-down cultivation is not encouraged (Panagos et al., 2015c), nevertheless such orientation of vine rows is still used also on steep slopes in North Italy (Biddoccu et al., 2017b) and in other regions in Europe (Rodrigo Comino et al., 2015) and in the Mediterranean basin (Ramos et al., 2015; Pipan and Kokalj, 2017).

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4. CONCLUSIONS

This study aimed at assessing the effects on runoff and soil loss of inter-row management (soil tillage and grass cover) and row arrangement (rows arranged along contour lines and up-and-down the slope) during three types of rainfall events ("intense", "long-lasting" and "normal"), comparing two study sites with similar conditions, in hillslope vineyards in Nort-Italy.

The most relevant contribution of this study is the assessment of the effect of role of rows orientation, on runoff and soil erosion comparing similar soil management and slope in vineyards located in the same region. The results of the study support the positive effect of contouring as a measure to prevent runoff and to reduce soil loss, even when soil tillage is adopted. Hence vines arrangements along contour lines associated with inter-row grass covering could be effective agricultural conservation measures to maintain Good Agricultural Environmental Conditions (GAEC), especially in hilly areas. Concerning the inter-row management, in accordance with the relevant literature, this study highlighted the effectiveness of grass cover with respect to soil tillage) in preventing runoff and soil erosion in sloping vineyards. Anyway, the extent of grass cover effectiveness varied according to the characteristics of the rainfall event and in relation to rows orientation.

The analysis of rainfall characteristics confirmed that few "extreme" rainfall events may be crucial in affecting overall mean values of soil loss and runoff rates, especially when the soil is bare or poorly protected by cover due to tillage or seasonal effect on the grass cover. Indeed, although the response of the vineyard in terms of runoff and soil erosion is the result of several factors (i.e. rainfall characteristics, soil management, seasonal variability), rainfall depth, primarily, and then rainfall maximum intensity resulted the most important rainfall variables in predicting the extent of runoff and soil loss.

Furthermore, results of the study, consisting in mid and long-term field observations in hillslope Mediterranean vineyards could be applied to implement or validate soil erosion models that represents

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useful tool for policy makers to simulate policy relevant scenarios to evaluate the effect of GAEC implementation.

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FIGURE CAPTIONS

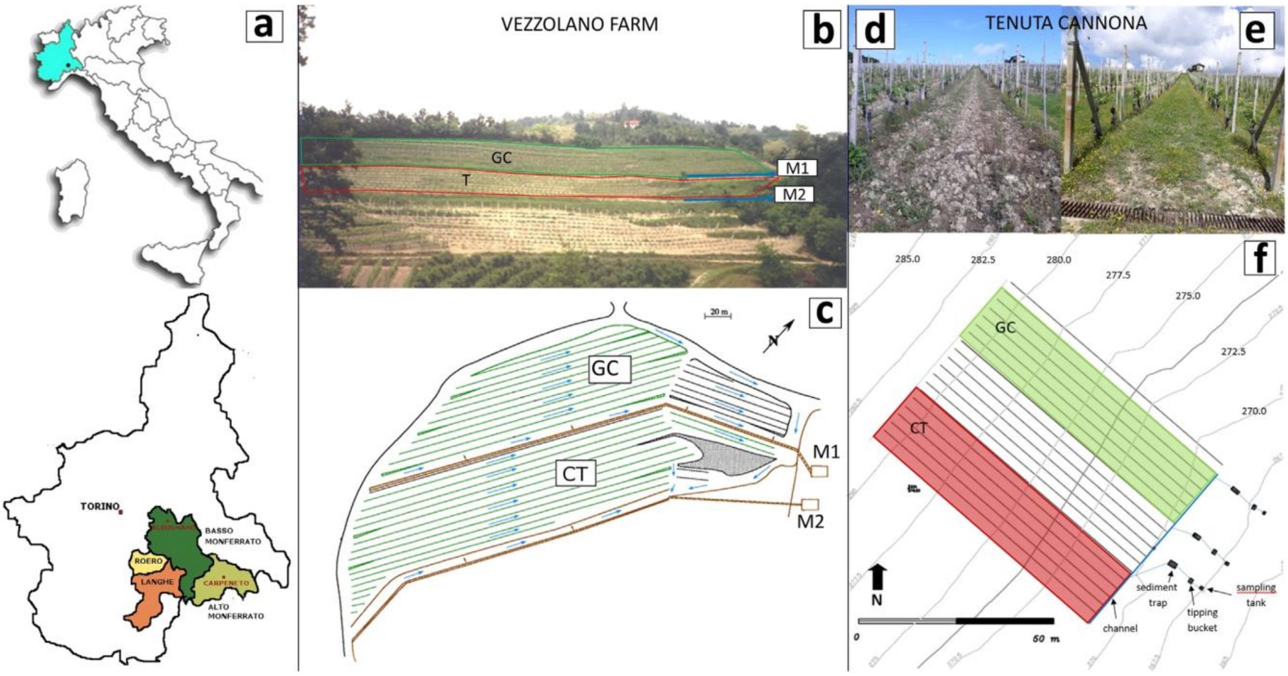

Figure 1. Study sites: a) localization of the study sites in Italy; views of: the vineyard monitored in the Vezzolano farm (b) a tilled (e) and a grassed (b) inter-row of the Tenuta Cannona experimental vineyard; a schematic representation of the Vezzolano (c) and Tenuta Cannona (f) monitored plots and runoff collection and measurement systems. GC indicates the plots with soil managed with controlled grass cover, CT indicates the plots with soil managed with tillage. M1 and M2 indicates the measurement devices.

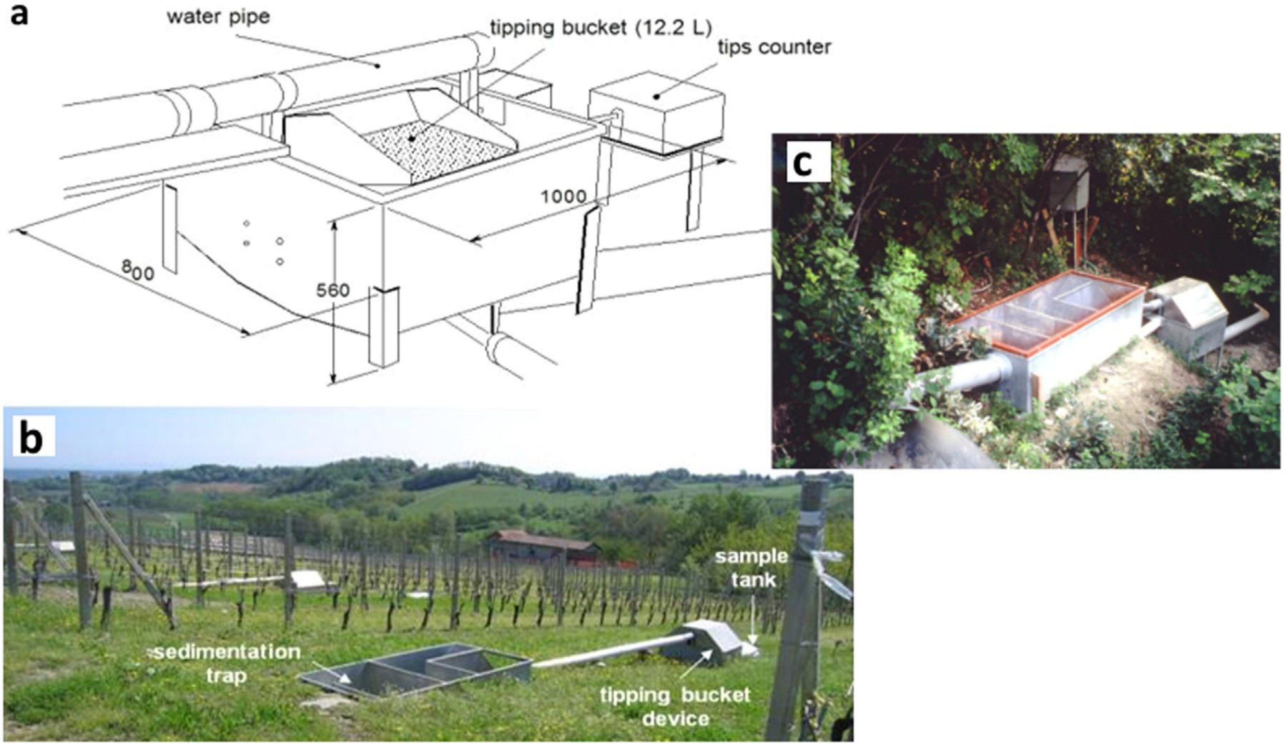

Figure 2: The runoff measuring system: a) schematic representation of the tipping bucket measurement devices; views of the sedimentation traps and the tipping buckets at the Tenuta Cannona experimental site (b) and at Vezzolano (c).

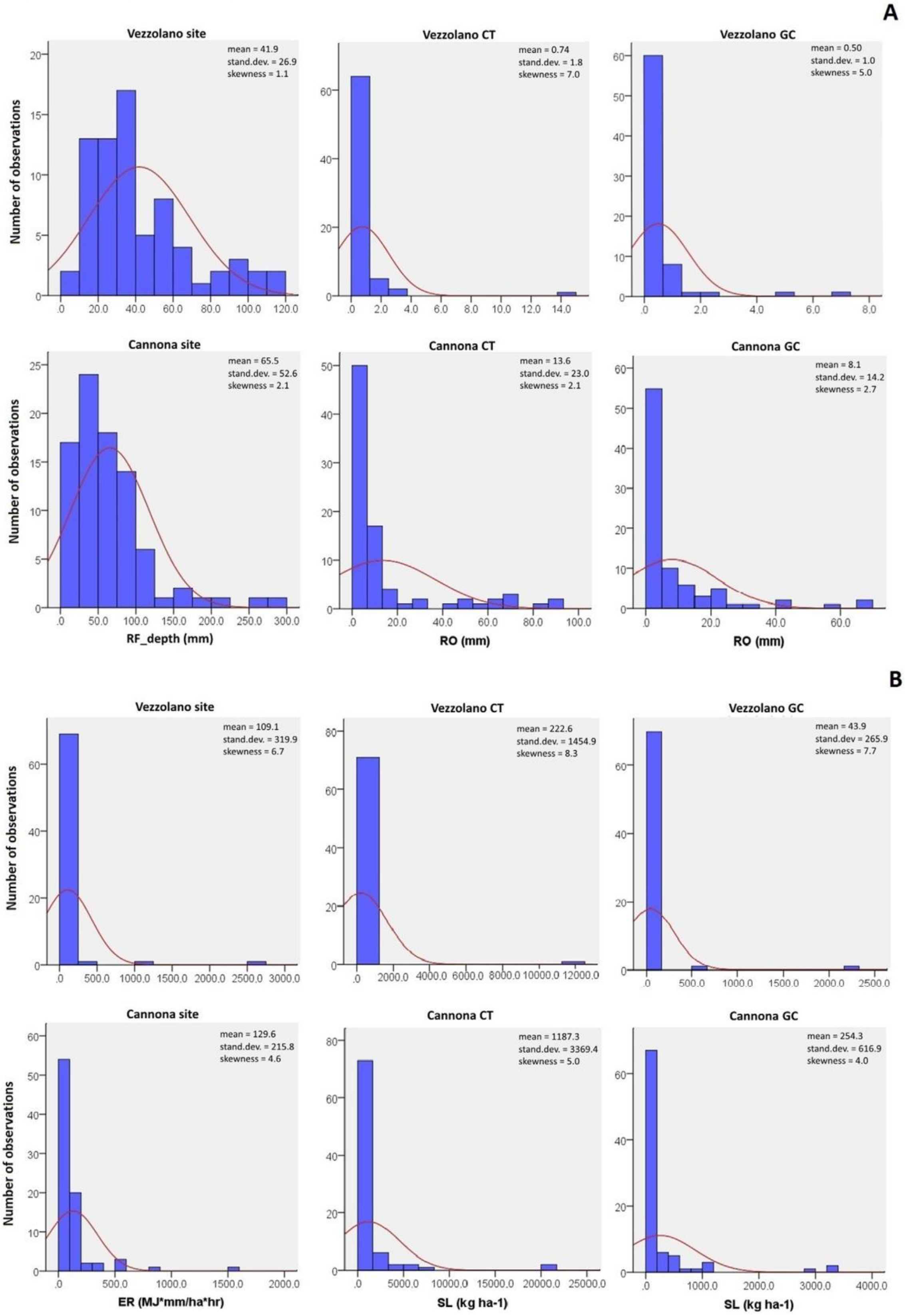

Figure 3. Frequency distribution of (a) event rainfall and runoff depth, and (b) rainfall erosivity and soil losses, for the two sites.

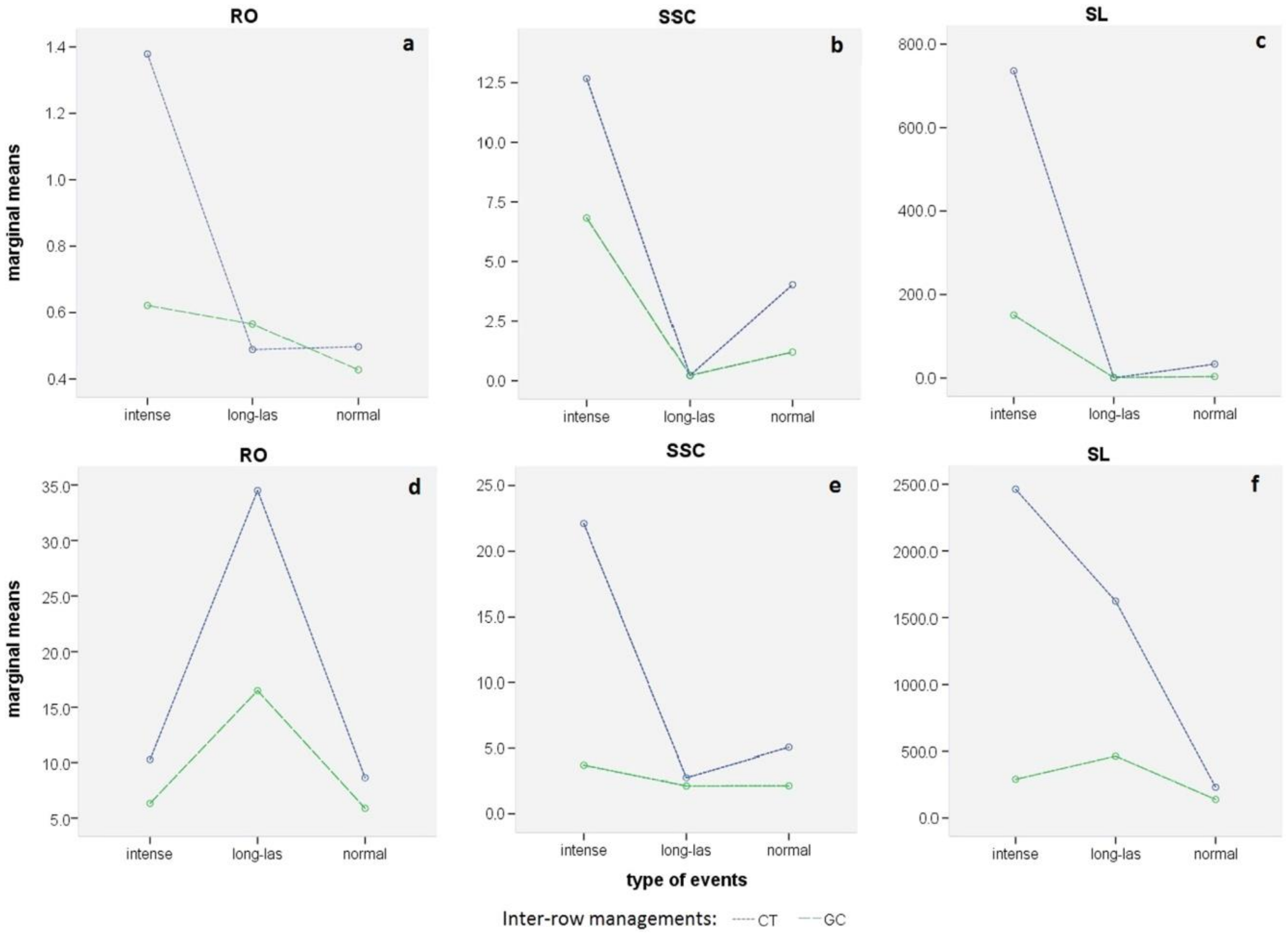

Figure 4. Profile plots obtained from 2-way ANOVA for the Vezzolano and Tenuta Cannona sites, representing the effect of management and event type on runoff (a), soil sediment concentration (b) and soil losses (c).

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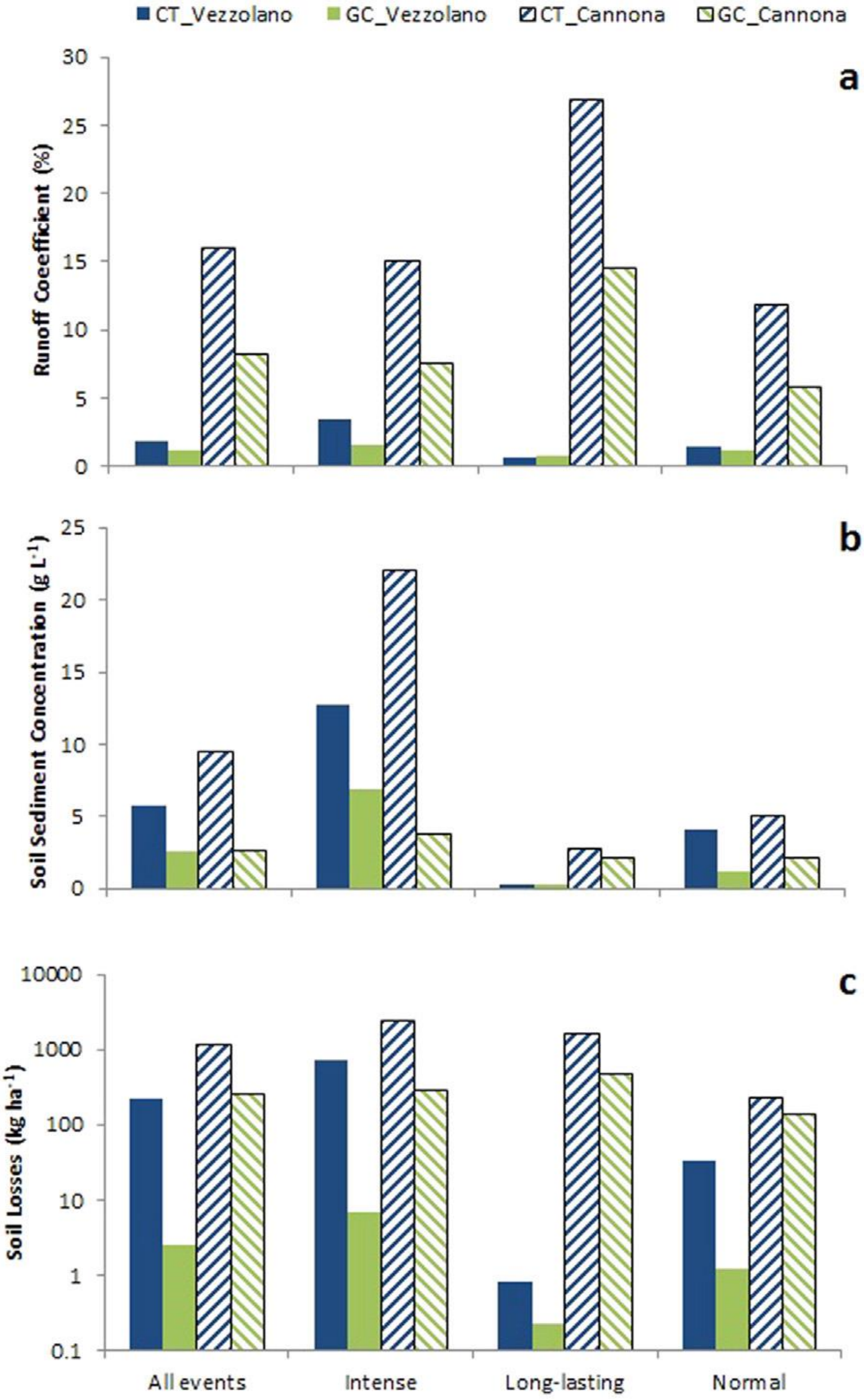

Figure 5. Comparisons of mean runoff coefficient (a), soil sediment concentration (b) and soil losses (c) between the different row disposition systems: Vezzolano (rows along contour lines) and Tenuta Cannona (rows up and down the slope).

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Table 1. Summary of mean values and coefficient of variation (CV%) of rainfall variables at event scale in the two experimental sites.

		Vezzolano experimental site (n=72)						Cannona experimental site (n=86)					
Type of event		n	RF_depth mm	RF_duration hrs	RF_Imax30 mm h^{-1}	RF_Imed mm h^{-1}	EI30 MJ mm ha^{-1} h^{-1}	n	RF_depth mm	RF_duration hrs	RF_Imax30 mm h^{-1}	RF_Imed mm h^{-1}	EI30 MJ mm ha^{-1} h^{-1}
All events	Mean	72	41.9	24.0	17.4	3.9	109.1	86	65.5	32.2	14.7	4.0	127.3
	CV (%)		64.3	111.2	133.9	123.6	293.2		79.6	88.6	85.9	147.0	174.8
Intense	Mean	20	31.7	6.9	42.9	7.8	143.7	25	54.0	14.4	28.5	8.2	268.1
	CV (%)		46.2	81.9	75.7	97.2	172.3		98.1	117.1	54.9	116.7	137.4
Long-“	Mean	13	77.6	72.3	5.8	1.1	50.8	19	111.6	74.9	8.4	1.5	106.2
	CV (%)		31.0	35.1	56.0	28.7	57.3		51.7	28.5	51.9	46.1	122.4
Normal	Mean	39	35.6	16.6	8.2	3.0	110.8	42	50.4	25.5	9.3	2.7	57.75
	CV (%)		64.9	31.0	40.3	80.8	359.4		66.8	61.0	39.1	65.6	107.2

Note: RF_depth: rainfall depth (mm); RF_duration: rainfall duration (hrs); RF_Imax30: maximum rainfall intensity over a 30-min period (mm h^{-1}); RF_Imed: medium rainfall intensity (mm h^{-1}), EI30: rainfall erosivity (MJ mm ha^{-1} h^{-1}).

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Table 2. Summary of mean values and coefficient of variation (CV, %) at event scale of run-off and sediment yield variables in Vezzolano and Cannona experimental sites. Bold values indicate significant differences between treatments according to Wilcoxon Signed Ranks Test at p = 0.05 level.

			CT					GC				
Site	Type of event		n	RO mm	RC %	SSC $g\ L^{-1}$	SL $kg\ ha^{-1}$	n	RO mm	RC %	SSC $g\ L^{-1}$	SL $kg\ ha^{-1}$
Vezzolano	All events	Mean	72	**0.74**	1.8	5.74	**222.61**	72	**0.51**	1.2	2.59	**43.97**
		CV (%)		240.4	186.9	259.3	653.6		208.9	185.0	264.4	604.9
	Intense	Mean	20	**1.38**	3.5	12.68	**735.90**	20	**0.62**	1.6	6.83	**150.59**
		CV (%)		232.8	166.1	160.7	371.7		192.0	136.4	175.0	330.5
	Long-lasting	Mean	13	0.49	0.6	0.23	0.83	13	0.57	0.7	0.23	1.11
		CV (%)		65.9	63.1	77.6	84.1		82.3	70.6	95.0	91.4
	Normal	Mean	39	**0.50**	1.4	4.03	33.32	39	**0.43**	1.1	1.21	3.58
		CV (%)		133.6	117.4	322.1	449.5		266.1	227.8	143.5	174.2

Cannona	All events	Mean	86	**65.55**	16.0	**9.51**	**1187.31**	86	**8.12**	8.3	**2.62**	**254.32**
		CV (%)		169.2	131.9	255.1	283.8		174.4	115.6	42.2	115.6
	Intense	Mean	25	**56.04**	15.0	**22.07**	**2462.08**	25	**6.32**	7.6	**3.74**	**289.64**
		CV (%)		161.9	194.4	180.8	175.3		194.4	94.6	17.5	94.6
	Long-lasting	Mean	19	**111.63**	26.8	2.78	1624.39	19	**19.12**	14.6	2.15	462.95
		CV (%)		101.8	106.2	236.4	300.6		106.2	70.1	187.2	70.1
	Normal	Mean	42	**50.37**	11.8	**5.07**	**230.79**	42	**4.22**	5.8	**2.16**	**138.91**
		CV (%)		218.1	202.5	226.3	170.2		202.5	161.7	67.1	161.7

Note: RO: runoff depth (mm); RC: runoff coefficient (%); SSC: soil sediment concentration (g L^{-1}); SL: soil loss (kg ha^{-1}).

Table 3. Pearson correlation matrix between runoff and erosion variables and characteristics of rainfall events for conventional tillage (CT) and grass cover (GC) inter-row management in Vezzolano (n = 72) and Tenuta Cannona (n = 86) experimental sites.

			CT					GC				
			RF_depth	RF_duration	RF_Imax30	RF_Imed	EI30	RF_depth	RF_duration	RF_Imax30	RF_Imed	EI30[a]
Vezzolano	All events	RO	0.157	-0.075	0.695**	0.121	0.108	0.228	0.015	0.401**	0.100	0.079
		SSC	-0.117	-0.244*	0.607**	0.350	0.105	-0.008	-0.225	0.761**	0.405	0.227
		SL	0.047	-0.082	0.710**	0.077	0.094	0.080	-0.091	0.776**	0.164	0.172
	Intense	RO	0.483*	0.122	0.811	0.011	0.308	0.557*	0.030	0.880**	0.171	0.485*
		SSC	0.465*	0.065	0.743	0.134	0.389	0.556*	-0.096	0.747**	0.247	0.583**
		SL	0.426	0.158	0.795**	-0.045	0.210	0.533*	0.105	0.866**	0.057	0.403
	Long-lasting	RO	0.230	-0.253	-0.044	0.537	0.348	0.384	-0.228	-0.026	0.607*	0.349
		SSC	0.030	-0.171	0.140	0.047	0.270	0.067	-0.052	-0.179	-0.061	0.012
		SL	0.152	-0.283	0.148	0.390	0.596*	0.433	-0.174	0.025	0.515	0.471
	Normal	RO	0.488**	0.142	-0.084	0.059	0.488**	0.208	0.085	-0.158	-0.022	-0.053
		SSC	-0.201	-0.335*	0.392*	0.535**	-0.201	-0.165	-0.393*	0.505**	0.574**	-0.079

		SL	-0.140	-0.238	0.295	0.206	-0.140	0.211	0.079	0.286	0.117	-0.059
Cannona	All events	RO	0.706**	0.551**	-0.017	-0.053	0.434**	0.837**	0.542**	0.030	-0.028	0.628**
		SSC	-0.112	-0.275*	0.514**	0.228*	0.130	-0.089	-0.250*	0.157	0.307**	0.064
		SL	0.316**	-0.026	0.537**	0.249*	0.428**	0.420**	0.093	0.209	0.214*	0.345**
	Intense	RO	0.865**	0.465*	0.097	0.021	.899**	0.941**	0.518**	0.101	0.023	0.949**
		SSC	-0.147	-0.295	0.468*	0.066	-0.109	-0.306	-0.436*	0.000	0.347	-0.211
		SL	0.066	-0.230	0.662**	0.201	0.298	0.278	-0.155	0.581**	0.557**	0.582**
	Long-lasting	RO	0.637**	0.440	0.386	0.449	0.477*	0.838**	0.423	0.567*	0.666**	0.871**
		SSC	0.672**	0.047	0.680**	0.698**	0.916**	-0.039	-0.177	0.005	0.044	0.042
		SL	0.709**	0.055	0.674**	0.732**	0.922**	0.365	-0.113	0.375	0.449	0.555*
	Normal	RO	0.444**	0.294	-0.056	0.008	0.274	0.602**	0.320*	0.099	0.102	0.546**
		SSC	-0.180	-0.311*	-0.095	0.280	-0.030	0.123	-0.341*	0.239	0.577**	0.637**
		SL	0.117	-0.202	0.049	0.347*	0.369*	0.558**	0.025	0.208	0.368*	0.813**

Correlation is significant at the 0.01 level for ** and at the 0.05 level for *. [a] Pearson correlation values for EI30 are computed for Cannona experimental site without events no. EC2- EC3-EC4-EC9-EC10-EC11-EC15-EC17-EC18-EC19-EC20-EC23-EC9 (n = 73).

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Table 4. Summary of the stepwise multiple linear regression model for runoff and sediment yield parameters in the two plots (CT e GC) of Vezzolano and Tenuta Cannona experimental site.

Site	Soil management	Dependent variable	Multiple regression equation	p-value	R^2
Vezzolano	CT	RO	-0.830 + 0.055 (RF_Imax30) + 0.015 (RF_depth)	< 0.001	0.533
		SSC	-1.003 + 0.338 (RF_Imax30)	< 0.001	0.368
		SL	-548.718 + 44.308 (RF_Imax30)	< 0.001	0.504
	GC	RO	-0.271 + 0.019 (RF_Imax30) + 0.011 (RF_depth)	< 0.001	0.232
		SSC	-1.301 + 0.224 (RF_Imax30)	< 0.001	0.579
		SL	-176.452 + 9.014 (RF_Imax30) + 1.515 (RF_depth)	< 0.001	0.625
Cannona	CT	RO	-5.955 + 0.292 (RF_depth)	< 0.001	0.449
		SSC	-0.082 + 0.427 (RF_Imax30)	< 0.050	0.112
		SL	-1695.169 + 23.400 (RF_depth) + 76.418 (RF_Imax30)	< 0.001	0.284
	GC	RO	-6.664 + 0.215 (RF_depth)	< 0.001	0.703
		SL	-138.758 + 5.658 (RF_depth)	< 0.001	0.198

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