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# Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany)

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## Abstract

Vineyards are one of the most German conditioned eco-geomorphological systems by human activity. Precisely, the vineyards of the Ruwer Valley (Germany) is characterized by high soil erosion rates and rill problems on steep slopes (between 23–26°) caused by the increasingly frequent heavy rainfall events, what is sometimes enhanced by incorrect land use managements. Soil tillage before and after vintage, application of vine training systems and anthropic rills generated by wheel tracks and footsteps are observed along these cultivated area. The objective of this paper is to determine and to quantify the hydrological and erosive phenomena in two chosen vineyards, during diverse seasons and under different management conditions (before, during and after vintage). For this purpose, a combined methodology was applied. Investigating climatic, pedological, geomorphological and botanic-marks variables was suggested on the two experimental plot in the village of Waldrach (Trier, region of Rhineland-Palatinate). First, high infiltration rates (near 100 %) and subsurface flow was detected by rainfall simulations performed at different times of the year. The second method to investigate the geomorphological response of slope inclination, two 10 m and one 30 m long rills were measured using geometrical channel cross-section index, depth and width. The highest variations (lateral and frontal movements) were noted before and during vintage, when footsteps occurred in a concentrated short time. Finally, two maps were generated of soil loss, indicated by the botanic marks on the graft union of the vines. As results 62.5 $t^{-1}$ $ha^{-1}$ $yr^{-1}$ soil loss rate was registered (one year) on the experimental plots of the new vineyards, while 4.3 $t^{-1}$ $ha^{-1}$ $yr^{-1}$ on the old one.

## 1 Introduction

Traditionally vineyards are one of the most conditioned eco-geomorphological systems by human activity. Cerdan et al. (2006, 2010) claimed, after studying 1350 experimental plots from several authors, that among cultivated areas, vineyards possess the highest erosion rates in Europe (12.2 t ha$^{-1}$ yr$^{-1}$). These problems appear at marginal lands with steep slopes, with bare soil cover and unsustainable management of soil structure (Martínez-Casasnovas et al., 2003; Paroissien et al., 2010).

On the steep slopes in the European viticulture, terracing was the dominant correcting measure (Petit et al., 2012). However, these erosive processes affect with equal or more intensity by several causes. Flow direction and rhythms of erosive process are manifested with several rills (with similar sizes), which divide the hillslopes in different transects (Bryan, 2000; Prashun, 2011). This pattern of parallel rills (Ludwig et al., 1995) shows the degradation processes on the vineyards, caused by water. Moreover, other potential and vulnerable areas are also affected by anthropic activities (Sánchez-Moreno et al., 2012). Vandekerckhove et al. (1998) concluded that erosion rates are enhanced by incorrect land practices by vine-growers, and they are particularly higher after heavy and concentrate rainfall events. For example, Mediterranean vineyards have the highest soil losses as a result of the increased surface flow rates by the soil texture (Kosmas et al., 1997).

According to the methodology and the concrete study areas, erosion rates are very variable: Martínez-Casasnovas and Poch (1998) and Martínez Casasnovas et al. (2002) in north Spain observed 207 and 302–405 t ha$^{-1}$ yr$^{-1}$ respectively; in northwest Italy, Tropeano (1983) estimated between 40 and 70 t ha$^{-1}$ yr$^{-1}$; Wicherek (1991) and Wainwright (1996) in France validated 30 t ha$^{-1}$ yr$^{-1}$.

In particular, Germany has a long tradition in viticulture and terraces on hillslopes along the Mosel, Ahr and Rhine Valleys. However, Unwin (1996) and Auerswald et al. (2009) reported several problems caused by erosion processes. The results from soil loss rates from German vineyards reflected several differences, from 0.2 (Richter, 1991) to 151 t ha$^{-1}$ yr$^{-1}$ (Emde, 1992).

For the Mosel Valley, different studies with experimental plots to explain the connection between precipitations (water and snow) and the soil loss behaviour by surface flow mechanisms carried out for the researchers of this department (Richter and Negendank, 1977; Richter, 1975, 1980a, b, 1991). Soils were characterized by increased infiltration rates, gravel and fine mobilized elements, high organic matter proportions and intensive use of agricultural machinery (Hacisalihoglu, 2007).

From an economic point of view, vineyards are a traditional form of land use, which conform one of the main and substantial economic bases of this region (Ashenfelter and Storchmann, 2010). The agricultural cultivation started in Roman times and continued with the constructions of monasteries in the middle Ages along Central Europe (Urhausen et al., 2011). These dynamic was significantly increased by the intensification of production and harmful tilling of the soil, which lead to a reduction of fertility (Boardman et al., 2003; Raclot et al., 2009). The process of expansion began in the 1950s and continued until the 1990s with some substantial transformations in the production methods by the introduction of new machinery (Martínez-Casasnovas et al., 2010). As a consequence, presence of gullies and rills, soil compaction and alteration of the local biochemical cycle were increased (Van Oost et al., 2007; Quinton et al., 2010).

The importance of land morphology (Fox and Bryan, 2000; Martínez-Casasnovas et al., 2010), soil surface components (Corbane et al., 2008; Ruiz-Sinoga and Martínez-Murillo, 2009) and the influence of hydrological properties (Arnáez et al., 2012) in cultivated and abandoned areas are noted by several authors. All this occurs as a trigger for the increased volume of soil loss and the heterogeneity of intra-plot situations (Brenot et al., 2008; Casalí et al., 2009). Erosive dynamics are revealed through different forms, for example like natural or anthropic rills and gullies (Poesen et al., 1998) or modern technics, like rainfall simulation. Small portable rainfall simulators, designed by Calvo et al. (1988) and advanced by Ries et al. (2009, 2013a, b) and Iserloh (2012), are essential tools to analyse the process dynamics of soil erosion and surface runoff in situ and in the laboratory. It provides the possibility to quantify soil erosion rates and to investigate the impact of several factors (slope, soil type, splash effect, raindrops, aggregate stability, surface structure and vegetation cover) on soil erosion with quick and reproducible measurements (Seeger, 2007; Iserloh et al., 2012, 2013a, b).

In concrete, almost all manifestations along the vineyards had the origins especially in footsteps and wheel tracks, which can significantly modify the natural dynamic of the hillslope (Van Dijck and van Asch, 2002; Materechera, 2009; Arnáez et al., 2012). Rills, inter-rills (Bryan, 2000; Fox and Bryan, 2000), and ephemeral gullies (Nachtergaele, 2001) show a connection between the lateral or vertical expansion (from 0.15 to 0.35 $m\,yr^{-1}$) and headcut retreat (about 0.7 $m\,yr^{-1}$) (Martínez-Casasnovas, 2003).

Therefore, the purpose of this study is to characterize this soil erosion process on vineyards, more precisely in the Ruwer Valley (Germany), where rill and inter-rill erosion appear. The objectives are: (i) to determinate the concrete hydrological and erosive response of soil; (ii) to describe and quantify the spatial and temporal development of rills during a particular period with natural rainfall events; (iii) to evaluate the impact of land use management before, during and after vintage in connection with rill erosion process; (iv) to compare the soil erosion rates between the recent and ancient vine cultivation, with the results of other locations with similar geomorphological characteristics. In essence, two spatial and temporal scales of analyses and, consequently, of erosive processes are considered: (i) local scale with simulated rainfalls and (ii) field scale with the monitoring of rills and quantification of soil loss through the botanic-marks.

## 2 Methods and data collection

### 2.1 Study area

The study area (Fig. 1) is located in the traditional vineyard village of Waldrach in the Ruwer Valley, an affluent of the Mosel River in West-Germany (Trier-Saarburg, Rhineland-Palatinate). It is part of the Rhenish Slate Mountains.

Two types of vineyards were studied: (i) one old (more of 35 years cultivated); (ii) one young (less than one year planted). Both have the same lithological characteristics. The Ruwer Valley descends from a plateau formed at the Hunsrück Mountains, from about

500 m.a.s.l. in the south to approximately 200 m.a.s.l. in the north (Richter, 1980b). Along this point, the parent material is composed by: (i) primary basin of no calcareous lithology under undulating reliefs with devonic greywackes, slates and quartzites; (ii) fines sediments near the Pleistocene rivers (Schröder, 1991).

The work area ranges from between 220 up to 250 m.a.s.l. The exposures of the hillslopes are fundamentally south-southwest oriented, for maximizing the insolation intensity and favouring the phenology of crops (Menzel, 2005).

In essence, the soil management techniques of vine-growers are composed of (Eggenberger et al., 1990; Vogt and Schruft, 2000): (i) soil tillage before and after vintage (end of October and beginning of November); (ii) presence of grass cover along the inter-rows and below grapevines (between 10–35 cm height); (iii) use of vine training systems to find equilibrium between leaves and the graft, to maximize photosynthesis and sugar creation, taking all of possible useful space along difficult steep slopes for tilling (between 23 and 36°).

Along the embankments and inter-rows, anthropic rills by wheel tracks and footsteps are noted. For example, the monitored rills of this investigation (R1, R2 and R3) are emplaced on the stony embankment (Fig. 1) and were generated by these causes.

Due to the lack of complete climatic station in the study area, values of rainfall and temperature (all with more than 30 years of data) must be extrapolated. Proximale stations in Mertesdorf (211 m; 49.7722, 6.7297), Hermeskeil (480 m; 49.6556, 6.9336), Trier-Zewen (131.5 m; 49.7325, 6.6133), Trier-Petrisberg (265 m; 49.7492, 6.6592), Trier-Irsch (228 m; 49.7259, 6.6957), Deuselbach (480.5 m; 49.7631, 7.0556), Konz (180 m; 49.6883, 6.5731), Bernkastel-Kues (120 m; 49.9186, 7.0664) and Weiskirchen (380 m; 49.5550, 6.8125) were applied. Data were obtained from the Deutscher Wetterdienst (DWD), which allowed to contextualize this territory with a Cfb climate (Köppen and Geiger, 1954). So, the obtained annual rainfall depth was 765 mm and was concentrated in the summer months (65–72 mm). The lowest monthly precipitation was observed between February–April (50–60 mm). Annual average temperatures was 9.3 °C,





SED
7, 259–299, 2015

with average maximum values in June, July and August (16.2–17.6 °C), and minimum values along January and December (1.5–2.3 °C).

### 2.2 Soil analysis

The soil samples were collected from four different positions. Two along inter-rows of old and young vineyards and two from the embankments of old grapevines with rills (top and bottom). Each sample was analysed with two replicates and different depths: 0–5 and > 5 cm (maximum to 15–25 cm). The samples were taken in order to determine the soil properties, such as pH, total organic carbon (TOC) and inorganic carbon (TIC) content by ignition (550 and 1050 °C respectively in muffle furnace), saturation and absorption capacity with drops of 1 mL each, bulk density using metal cylinder and grain size distribution using the methodology of Soil Survey Staff of USDA (2014).

### 2.3 Description of rainfall and agricultural events during the monitoring

Climatic and agricultural actions (concurrently with the monitoring) was monitored to describe the important events in the study area. In order to obtain the rainfall data, an extrapolation of the gradients data at surface level was made, by using the data from the peripheral agroclimatical stations of the Deutscher Wetterdienst (DWD) and the Dienstleistungszentrum Ländlicher Raum/Rheinland-Pfalz (DLR-RLP). Calculations were linear estimations and intersections with the axis, using rainfall and elevation data (Rodrigo Comino, 2013; Senciales and Ruiz Sinoga, 2013). Rainfall events were frequents during all the research period. The total average daily intensity in this period (September to December) was 2.2 mm $d^{-1}$ and days with rainfall was 4.6 days in each interval of this monitoring (between 6 to 7 days).

### 2.4 Statistical and spatial analysis

A continuation, *K* (with the soil analysis) and *R* factor of RUSLE (Wischmeier and Smith, 1978; Dabney et al., 2014) were added to complete the soil analysis erodibility and rainfall erosivity respectively as Martínez Casasnovas et al. (2002). For this purpose, *R* factor (54.31) was calculated with the index for Germany with better results than adjusted equation for Rhineland-Palatinate region (Sauernborn, 1994; Casper et al., 2013). After that following the example of Arnáez et al. (2007), recurrence periods with Poisson method were included to justify the intensity of rainfall simulation and classify rainfall events on the study area (Mays, 2011). Results are presented as percentage of days per year using a co-Kriging extrapolation with GIS from the peripheral agroclimatical stations.

### 2.4.1 Rainfall simulations

In alternate varying months, eight rainfall simulations were carried out under different soil moisture conditions. During the first four simulations in August (2012) the soil moisture were between 50–70 %, while October and December (2013) between 20–40 %. The objectives were to quantify the soil losses, the degree of infiltration, runoff coefficients, suspension and concentration of sediments. All simulations were carried out on the inter-rows of old-vineyards with the same rainfall intensity (40 $mm\,h^{-1}$) for two reasons. Firstly, when the return period is calculated, 40 $mm\,h^{-1}$ of intensity is the least usual. Therefore the most important extreme rainfall with some probability it happened on the study area, it would be not greater than 40 $mm\,h^{-1}$. So the different reactions of the soil with extreme rainfall could be note. Secondly, the simulator was exactly calibrated to control splash effects following Iserloh et al. (2012, 2013). The defined area of experiments coincided with a metal ring of 0.28 $m^2$. To measure the quantity of water a pump (maximal intensity of 1512 $L\,h^{-1}$) and a manometer (with a calibrated pressure of 0.2 bar) were applied. In each simulation (30 min), we were using intervals of 5 min to collect runoff.

From September the same results were obtained: total infiltration. The last one was carried out in December (2013) with another method.

To understand the reason of the 100 % infiltration, the stoney A horizon was removed inside the metal ring during the final simulation. The main purposes were to: (i) confirm the increased infiltration; (ii) investigate the relationship between the process and the soil surface components; (ii) investigate the relationship between the process and the soil surface components. A hydrophilic nylon fabric was used to protect the soil from the splash effect. A vertical soil profile was caved underneath the simulator (50 cm depth and 150 cm width) in order to observe the infiltration dynamic. In this manner, subsurface flow was observable (Fig. 2) by the profile and the metal collector, however it was impossible to quantify it.

### 2.4.2 Geometrical rills monitoring

Three rills with different geomorphological origin were chosen for the monitoring (R1, R2 and R3). The rills were divided into one meter sections. Between September and December, the width, depth and slope angle of the sections along three rills (R1, R2 and R3) were measured. The first rill (R1) was caused by the wheel tracks and it was nearly 30 m long (30 sections), starting from the bottom of the embankment. The average declination of the rill was 28° and had approximately a contributing area of 600 $m^2$. The second (R2) and third (R3) rills were located on the embankments with steeper slopes (34 and 31.7°) and had smaller contributing areas (19 and 25 $m^2$ respectively). R2 (near a wall and drainage channel) was 7 m length (7 sections) and, for his part, R3 around 10 m (10 sections). Both were caused by the footsteps of vine workers. The methods of Govers and Poesen (1987), Takken et al. (1999), Vandekerckhove et al. (2003) and Wirtz et al. (2012) were followed to measure their changes in geometry. In order to calculate weekly the geometrical variation of transects, the geometrical channel cross-section index was calculated (Dingdam, 2008):

$$\text{TSI} = W/Y$$

where $W$ represents the width and $Y$ the depth, both were measured in cm. Note, while the quotient is more elevated, widening process of rills is bigger than the deepening. Furthermore, standard deviation was added to distinguish when averages were obtained with equal or unequal values. Consequently, two types of analyses with the





SED
7, 259–299, 2015

geometrical channel cross-section index (Dingman, 2008) were elaborated. Inclination was measured with a clinometer.

First, during the monitoring total average values per section were used to detect temporally and spatially the most vulnerable and modified transects by geomorphological changes. The second calculation pretended to show the geometrical variation of each rill between the monitoring phases with the standard deviation (before, during and after vintage).

### 2.4.3 Frontal botanic marks on the graft union

The distance between frontal marks on the graft union and the visible actual rootstock of grape-vines were measured (Fig. 3) on a total area of 0.065 ha (with old grapevines) and on 0.043 ha (with young grapevines). Graft union can be defined as unearthing or buried signal, which could showed the theoretical ancient topsoil (Brenot et al., 2008). This analysis pretends to confirm the theory about the "botanic marks" as indicators of soil loss (Brenot et al., 2008; Casalí et al., 2009; Paroissien et al., 2010). *Vitis vinifera* after the *Phylloxera* crisis was grafted with the American scion of controlled species as the *Vitis rupestris, Vitis riparia* and *Vitis berlandieri* (Unwin, 1996). Several authors (Brenot et al., 2008; Casalí et al., 2009; Paroissien et al., 2010) demonstrated that these signals were correct indicators of soil movements in the vineyards (erosion, transport and sedimentation). The conditions described in Brenot et al. (2008), were previously confirmed with the vine-growers the conditions of: (i) there is no vertical growth of the graft after the vineyard plantation; (ii) the recommendations concerning the graft union elevation at the vineyard are followed so that this elevation can be considered to be constant over the studied region; (iii) the measurement errors are negligible compared to the observed unearthing or burying of vine-rootstock.

Furthermore all graft unions near 2 cm from the topsoil were planted during the first year. In total 1200 graft unions were measured with a subtraction of 2 cm, from which 720 were cultivated 35 years ago on the study area (coinciding with the monitored rills). The other 480 were planted in 2012. The average inclination of the hillslope is





SED
7, 259–299, 2015

almost constant from 22 to 24°. It is important to note that a little contention wall with a drainage vertical collector (adjacent to R2) divides the study area in two parts. This infrastructure was planned to reduce accumulation of the eroded materials along the road and to drain the possible surface flow. Below two isoline maps are presenting the soil erosion level, according to the geomorphological conditions of the plots. Co-kriging method (Dirks, 1998; Goovaerts, 1999; Wang et al., 2013) was applied with 0.1 precision intervals (quartiles) and two variables: botanic marks and digital elevation model with a resolution of 1 m × 1 m.

First, the total soil loss was calculated from the volume of an imaginary polygon and then it was extrapolated to $m^3 ha^{-1}$ and $t\,ha\,yr^{-1}$ with a lineal estimation. The sides of the polygon were the distance between each vine-stock (0.9 m × 1 m), while the height was the distance between the botanic marks on the graft union and the visible actual rootstock. Finally, total soil loss ($t\,ha^{-1}$) was estimated, using the volume and the bulk density data. For the young vineyards 1.14 $g\,cm^3$ and for the old one 1.4 $g\,cm^3$ were used, both the average of the two soil samples in different depth (0–5 and > 5 cm). At this level, this method also requires the assumption that the study area is absolutely flat. However, certainly due to the rills, footsteps and wheel tracks it is rough.

## 3 Results

### 3.1 Soil analysis

Laboratory analysis data (Table 1) show relevant chemical and physical properties of the soils from the study area. Stony soil, high organic matter (4.1 and 13.7 %) and several gravel material (58–70 %) were observed in the profile. The elevated water absorption capacity and the subsurface flow across the hillslope were ratified by the sandy-clay and clay texture. Finally with the help of these data, *Cambisol leptic-humic* was classified using the methodology of FAO (2006a, b, 2007).





SED
7, 259–299, 2015

The results of $K$ factor about erodibility of soil following Wischmeier and Smith (1978) and Dabney et al. (2014) showed 0.22 and 0.37 for old and young vineyards respectively.

### 3.2 Rainfall events and land management during the study period

Description of soil conditions, during and after the agricultural activity, and the extrapolated rainfalls in 2013 (total and intensity) from the nearby climate stations were described to add more information (Table 2). The probability of return period (Table 3) is added to include the recurrence of different rainfall depth and intensities per day.

During and one week after vintage a powerful anthropic action was observed. This situation coincided with the elevated soil moisture rates. The increased footsteps of the workers disturbed the soil (sub and superficially) therefore rills appeared. This dynamic was observed at areas without vegetation cover or not cultivation (e.g. embankments).

After vintage the number of footsteps was reduced, coinciding with the decreasing of rainfall depth and intensity (mm $d^{-1}$). Accordingly, less soil movement was observed and the rills began to widen. However, currently every morning the soil was frozen and along the day a thaw was occurred.

The precipitation between 20 and 5, and 5–0.1 mm $d^{-1}$ have the highest probability (36.1–36.3 and 22.6–23 % respectively). The more intense rainfall events (> 40 mm $d^{-1}$) have the lowest possibility. The probability of rainfall events at this time could be classified between a 22.7–23 %.

### 3.3 Rainfall simulations

In total, eight rainfall simulations were carried out during August, October, November and December (Table 4), but only the summer simulations gave quantifiable result about runoff and soil loss (Fig. 4). During the other simulations 100 % infiltration rate was observed.





SED
7, 259–299, 2015

For the four simulations of August, runoff and sediment suspension data appeared. The maximum runoff coefficient and suspension sediment were 15.2 ± 7.8 % and 25.81 $g\,m^{-2}$ respectively. These values were lower compared to the infiltration averages (near 100 %). In each experiment, only one increase interval of soil loss and at the same time more surface runoff was noted. Consequently, the sediment concentration decreased. Principally, this situation happened in the central minutes of the rainfall simulation (between 10 and 20 min), when the soil became saturated and expelled water as surface flow. After this saturation point, the A horizon was being eliminated and it seemed that the water could be moving as subsurface flow by gravity.

This supposition was confirmed in the next three simulations, because the rainfalls were completely infiltrated and fine sediments were not eroded. Finally, for the last simulation in December, a soil profile of 0.5 m below the simulator was excavated (Fig. 2) in order to observe the intensity and direction of this possible subsurface-flow. From the beginning of the simulation, this hydrodynamic behaviour was noted across the profile. However, we could not calculate the intensity and observe the direction in situ, because the water flowed across an area larger than the rainfall simulator collector.

### 3.4 Geometrical monitoring of rills with anthropic origin

Size variations of the rills are presented in graphics with data from the monitoring period (Figs. 5 and 6).

The highest variations were observed before and during vintage. When no footsteps occurred in a concentrated short time, soil reacted without lateral and frontal movements. Of this situation, the behaviour of the soil could be deduced with the deepening and widening process of the rills. In general, using the geometrical channel cross-section index, four intervals were detected with relevant weekly changes: (i) between 0–1 and 1–2 m (below the hillslope) irregularities were noted in little alluvial fans on the border of the embankment and the road; (ii) from 3–4 to 4–5 m fracture appeared in the slope as a micro-terraces (between 32 to 36° of slope), in which small slide scars by the soil movements were noticed below the A horizon; (iii) along 7th and 9th meter at the top of the embankment, where the vines grapes were cultivated (the slopes were 30 to 23°); (iv) only for R1 (originated by wheel tracks), it was noted an increase of the values of geometrical cross-section index from 26–27 m and a maintaining of the gradient (27–28°). In this section, in contrast to deepening process weeding was favoured, especially during the vintage. Moreover, average values (Figs. 7 and 8) in each rill with this index was noted.

For R2, higher value (5.3 ± 2.9 cm) was obtained than for R3 (4.9 ± 2.5 cm). In this regard, the most inconstant rill (R2) was located near a little contention wall with a drainage channel and it was significantly modified by several footsteps.

At R1 (5.3 ± 2.2 cm) between 1 and 10 m elevated data were observed (5.5 ± 2.9 cm), but from here the values were descended (5.3 ± 1.8 cm) was observed. Finally, the highest parameters were from 27 m (10.7 ± 4.6 cm) measured, during the weeding processes (confluence of two or more rills) were detected.

### 3.5 Soil loss level maps

Figures 9 and 10 present the soil losses and the trend of movements. Annual average soil loss per row, on each side of the contention wall and on the total study area was added to the final tables (Tables 5 and 6).

At each side of the channel, the contention wall at both vineyards diverse dynamics was noted. The highest erosion rates (dark colors) were located on the top at the left side of the hillslope. This situation was repeated near the channel in contact with the embankment (for the young grapevines 28.11 and 63.49 $t\,ha^{-1}$ in the old vineyard). The behavior is more in accordance with the natural conditions on the right side, because the soil loss was lower (light colors) and below the accumulation was predominant (during one year 6.31 $t\,ha^{-1}$ and in 35 years 37.87 $t\,ha^{-1}$).

In the first year of cultivation very high total soil loss was calculated (53.09 $t\,ha^{-1}$). However; for the old vineyards (35 years), 116.55 $t\,ha^{-1}$ erosion rate with an annual rate of 3.3 $t\,ha^{-1}\,yr^{-1}$ was calculated. Again, on the left side losses were bigger than on the right side (1.51 and 1.81 $t\,ha^{-1}\,yr^{-1}$).

## 4 Conclusions and discussion

This work presents the soil erosion problems of a vine cultivated study area from the Mosel Valley. Combined methodology with climate, pedology, geomorphology data and botanic marks was used. The results are reported according the following order: (1) soil analysis, (2) rainfall events and land management during the study period, (3) rainfall simulations, (4) geometrical monitoring of rills with anthropic origin and (5) soil loss level maps.

First of all, the hydrological response and the erodibility of the soil were determined by soil analysis, the observation of land management techniques and the rainfall simulations. Due to the stony soil conditions (between 58.3 and 70.7 % larger than 2 mm) and the active cultivation work (wheel tracks and footsteps along the inter-rows), high infiltration rates (near 100 %) and subsurface flow was observed. Although it was not possible to quantify the amount of transported fine sediment. During the sample analysis and the different experiment structural instability of the soil was observed: most probably due to: (i) subsurface processes, such as micro-piping or creeping (ii) the pedological conditions, like the high clay and gravel content or bulk density.

Secondly, spatial and temporal geometrical evolutions of rills were monitored before, during and after the agricultural activities (vintage) in the study area. Accordingly soils had three different responses in the three different situations. The biggest variability (in width and depth) of the rills was observed on the embankment close to the contention wall and drainage channel. Due to the work on the soil (land removal), plants with their roots holding the soil and the not sufficiently located wall, increase and development of the rills were noted. The footsteps and wheel tracks before and during vintage increased the dynamic of these processes. This was coinciding with the frequent and intensive rainfall events.

Moreover, the impact of land management was evaluated with the total soil losses rates, using the botanic marks of the grapes. The instructions of Brenot et al. (2008), Casalí et al. (2009) and Paroissien et al. (2010) was followed to measure the difference





SED
7, 259–299, 2015

in the graft union of 1200 grapevines. However, an elevate component of subjectivity is adverted by several authors, because the method depends of arbitrary criteria. With this method 116.6 $\mathrm{t\,ha^{-1}}$ soil loss was calculated on the old vineyard, which means 3.3 $\mathrm{t\,ha^{-1}\,yr^{-1}}$. Respectively in the first year on the young vineyard 53.1 $\mathrm{t\,ha^{-1}}$ was measured, which is much more than the yearly average.

Finally, these results of the erosion rates were compared with other studies about vineyards in the Mosel Valley, Germany and Europe by different authors (Table 7).

As this study, Richter (1975, 1991) and Hacisalihoglu (2007) worked also in the Ruwer Valley vineyards context, but with different methodologies. In these experiments they were using sediment boxes and empiric equations, but the measured soil loss rates were were similar to the erosion rates of the old vineyards of this paper (3.3 $\mathrm{t\,ha^{-1}\,yr^{-1}}$) 0.2–6.6 and 6.47 $\mathrm{t\,ha^{-1}\,yr^{-1}}$, respectively. For other scales (Germany and Europe), Auerswald et al. (2009) and Cerdan et al. (2006, 2010) calculated similar soil erosion rates as well (5.2 and 12.2 $\mathrm{t\,ha^{-1}\,yr^{-1}}$), with extrapolations from different works.

Only Emde (1992) with USLE inferred a rate over 150 $\mathrm{t\,ha^{-1}\,yr^{-1}}$, which is approximated to the soil erosion of the young grapevines (53.1 $\mathrm{t\,ha^{-1}\,yr^{-1}}$) in this paper.

The results of this paper contribute the validity of the available data, although the comparability with other studies is difficult, due to the different methodological approaches and the diverse climatic situations. Furthermore, all studies coincided in the same assumption: the vineyards soil erosion rates were the highest compare to other land uses (forest, grassland, shrubs or regeneration).

For a correct land management, the location, the quantification and the proposition of measures for the prevention of the destabilizations and modifications on hillslopes are considered to be essential. Territories with intensive and mountain farming should be considered as vulnerable points by erosion problems. Policies must aim to protect hillslope morphologies for terracing and to prohibit indiscriminate heavy machinery use. Alterations can implicate changes with unappreciable consequences in short-term, but irreversible in long-term (Piccarreta et al., 2006).





SED
7, 259–299, 2015

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SED
7, 259–299, 2015

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SED

7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

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SED
7, 259–299, 2015

**Table 1.** Soil analysis of the study area.

| | Texture analysis | | | | | Other properties | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil samples | > 2 mm (% Total) | < 2 mm (% Total) | Sand % (2–0.2 mm) | Silt % (0.2–0.63 mm) | Clay % (< 0.063 mm) | pH | TOC (%)[a] | TIC (%)[b] | Saturation (%)[c] | Absorption capacity (%)[d] | Bulk density ($g\,cm^{-3}$) |
| Old grapevines (0–5 cm) | 68.18 | 31.82 | 49 | 14 | 37 | 6.6 | 10.7 | 1.5 | 11.3 | 12.7 | 1.4 |
| Old grapevines (5–15 cm) | 66.19 | 33.81 | 44 | 11 | 45 | 6.6 | 6.5 | 1.5 | 9.8 | 10.9 | 1.4 |
| Over embankment (0–5 cm) | 61.45 | 38.55 | 58 | 15 | 27 | 6.7 | 13.7 | 1.5 | 10.1 | 11.2 | 1.4 |
| Over embankment (5–15 cm) | 58.25 | 41.75 | 52 | 14 | 34 | 6.3 | 6.6 | 2.2 | 11.2 | 12.6 | 1.4 |
| Below embankment (0–5 cm) | 61.82 | 38.18 | 45 | 11 | 44 | 6.4 | 5.7 | 1.3 | 9.1 | 10 | 1.3 |
| Below embankment (5–15 cm) | 68.85 | 31.15 | 47 | 11 | 42 | 6.7 | 5.7 | 1.4 | 11.8 | 13.4 | 1.4 |
| Young grapevines (0–5 cm) | 70.17 | 29.83 | 47 | 12 | 41 | 6.6 | 4.1 | 2.3 | 11 | 12.5 | 1.1 |
| Young grapevines (5–15 cm) | 70.68 | 29.32 | 46 | 11 | 43 | 6.1 | 5.5 | 1.5 | 12.7 | 14.5 | 1.2 |

[a] TOC = Total Organic Carbon; [b] TIC = Total Inorganic Carbon; [c] Saturation (%) = (Water added to saturation/final weighted) × 100; [d] Absorption capacity (%) = (Weighted of saturated aggregate − Initial weighted)/initial weighted × 100.



SED
7, 259–299, 2015

**Table 2.** Rainfall events and agricultural activities descriptions during the monitoring.

| Monitoring phase | Date | Rainfall (mm)[a] | Days with rain | Intensity (mm $d^{-1}$) | Activities |
|---|---|---|---|---|---|
| Before vintage | 24 Sep 2013<br>1 Oct 2013<br>8 Oct 2013 | 22.98<br>10.34<br>1.25 | 6.6<br>4.3<br>2.5 | 3.3<br>1.5<br>0.2 | Leaves of the grapevines were cut to improve the absorption of the sunlight and appearance of footsteps. |
| Vintage | 15 Oct 2013<br>22 Oct 2013<br>29 Oct 2013 | 22.78<br>26.63<br>8.78 | 3.3<br>4.1<br>4.9 | 3.3<br>3.8<br>1.3 | Several footsteps marks were situated from the sections 0–1 to 8–9 m. A lot of grapes and leaves stayed on the surface. |
| After vintage | 6 Nov 2013 | 51.40 | 5.9 | 7.3 | Several footsteps modified R2. It increased lateral enlargement (no deepening). |
| | 12 Nov 2013 | 33.96 | 4.5 | 4.9 | Many grape-leaves and branches on the surface. Footsteps began to dissolve on monitored rills (1, 2 and 3). |
| | 19 Nov 2013 | 10.34 | 6.3 | 1.5 | The soil was cleaned from leaves and branches. Footsteps were joined in form of new rills by the rainfall. |
| | 26 Nov 2013<br>03 Dec 2013 | 1.95<br>7.96 | 4.0<br>4.8 | 0.3<br>1.1 | Each morning soil freeze appeared. After midday it was almost dry, but not the subsurface horizons. |
| | 10 Dec 2013 | 3.24 | 4.3 | 0.5 | Footsteps marks were visible only from the sections 0-1 to 1-2. Rills stayed without remarkable changes. |

[a] Rainfall (mm) means total mm after each measure, currently, each 6 or 7 days.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

**Table 3.** Return period of rainfall events per year.

| Rainfall depth (mm) | % probability of return period ($d^{-1}$ $y^{-1}$) |
|---|---|
| > 40 | 0.44–0.46 |
| 40–20 | 5.65–7.23 |
| 20–5 | 36.12–36.36 |
| 5–0.1 | 22.67–22.95 |
| 0 | 9.02–11.16 |





SED
7, 259–299, 2015

**Table 4.** Rainfall simulation parameters.

| ID | Pp ($mm\,h^{-1}$) | Runoff (L/5 min) | Runoff Coef./5 min (%) | Infiltration/5 min (%) | Concentration/5 min ($g\,L^{-1}$) | Total erosion ($g\,m^{-2}\,h^{-1}$) |
|---|---|---|---|---|---|---|
| 1 Aug 2012 | 9.72 | 0.03 ± 0.01 | 3.9 ± 1.1 | 96.1 ± 1.1 | 3.34 ± 1.95 | 23.2 |
| 2 Aug 2012 | 10.32 | 0.004 ± 0.002 | 0.52 ± 0.2 | 99.5 ± 0.2 | 5.03 ± 2.91 | 30.9 |
| 3 Aug 2012 | 13.2 | 0.17 ± 0.09 | 15.2 ± 7.8 | 84.8 ± 7.8 | 7.77 ± 3.07 | 51.5 |
| 4 Aug 2012 | 10.44 | 0.06 ± 0.04 | 6.7 ± 4.8 | 93.3 ± 4.8 | 7.01 ± 8.03 | 30.5 |
| 5 Oct 2013 | 10.8 | 0 | 0 | 100 | 0 | 0 |
| 6 Oct 2013 | 10.68 | 0 | 0 | 100 | 0 | 0 |
| 7 Nov 2013 | 11.16 | 0 | 0 | 100 | 0 | 0 |
| 8[a] Dec 2013 | 9.48 | 0 | 0 | 100 | 0 | 0 |

[a] = Rainfall simulation without A horizon.



Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

SED

7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

**Table 5.** Volume estimations of soil loss in young vineyard.

| Soil decapitation (areas) | $m^3 ha^{-1}$ | $t ha^{-1}$ [a] |
|---|---|---|
| Soil loss/row | 5.9 | 6.7 |
| Left side of the channel/row | 6.2 | 7.1 |
| Right side of the channel/row | 5.5 | 6.3 |
| Total on the left side | 24.7 | 28.1 |
| Total on the right side | 21.9 | 25 |
| Total soil loss | 46.6 | 53.1 |

[a] $t ha^{-1}$: The soil loss is equivalent to the total erosion since the first moment of plantation.





SED
7, 259–299, 2015

**Table 6.** Volume estimations of soil loss in old vineyard.

| Soil decapitation (areas) | $m^3 ha^{-1}$ | $t ha^{-1}$ | $t ha^{-1} yr^{-1}$ |
|---|---|---|---|
| Soil loss/row | 6.9 | 9.7 | 0.3 |
| Left side of the channel/row | 7.6 | 10.6 | 0.3 |
| Right side of the channel/row | 6.3 | 8.8 | 0.3 |
| Total on the left side | 45.3 | 63.5 | 1.8 |
| Total on the right side | 37.9 | 53.1 | 1.5 |
| Total soil loss | 83.3 | 116.6 | 3.3 |

[a] The divisor is 35 (years of the plantation).





SED
7, 259–299, 2015

**Table 7.** Comparison of soil losses rates between different uses, territories and methodologies.

| Authors | Study area | Method | Rates ($t\,ha^{-1}\,yr^{-1}$) | Types of land uses |
|---|---|---|---|---|
| Richter (1975, 1991) | Mertesdorf (Mosel Valley) | Sediment boxes | 0.2–6.6 | Vineyards |
| Emde (1992) | Rheingau (Rhin Valley) | USLE | 151 | Vineyards |
| Hacisalihoglu (2007) | Mertesdorf (Mosel Valley) | "Algemeine Boden Abtrags Gleichung" (ABAG) | 0.71<br>0.67<br>0.87<br>1.2<br>6.47 | Regeneration<br>Forest<br>Shrubs<br>Grassland<br>Vineyards |
| Auerswald et al. (2009) | Germany | Extrapolations and *R* factor of USLE (Universal Soil Loss Equation) | 5.7<br>0.5<br>0.2<br>5.2 | Annual arable land<br>Grassland<br>Forest<br>Vineyards |
| Cerdan et al. (2006, 2010) | Europe | Extrapolations from other works | 12.2 | Vineyards |
| This study | Waldrach (Mosel Valley) | Botanic marks | 3.3–53.1[a] | Vineyards |

[a] 3.3 $t\,ha^{-1}\,yr^{-1}$ on the old vineyards (average in 35 years) and 53.1 $t\,ha^{-1}\,yr^{-1}$ for the other area with young grapevines (since 2012).





SED
7, 259–299, 2015

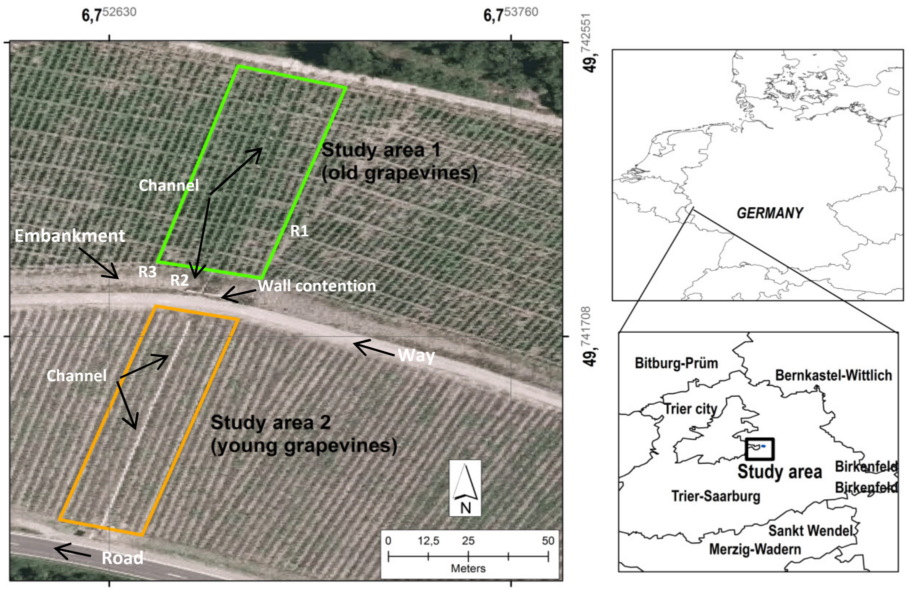


**Figure 1.** Study area in Waldrach (Ruwer Valley, Germany).





SED
7, 259–299, 2015


**Figure 2.** The rainfall simulation in December. **(a)** A horizon eliminated (between 5–7 cm). **(b)** Before simulation. **(c)** Profile to 0.5 m below (1.5 m × 0.5 m) with the sediment collector. **(d)** Situation of simulator ring. **(e)** Concurrently rainfall simulation. **(f)** Subsurface flow during the experiment.





SED
7, 259–299, 2015

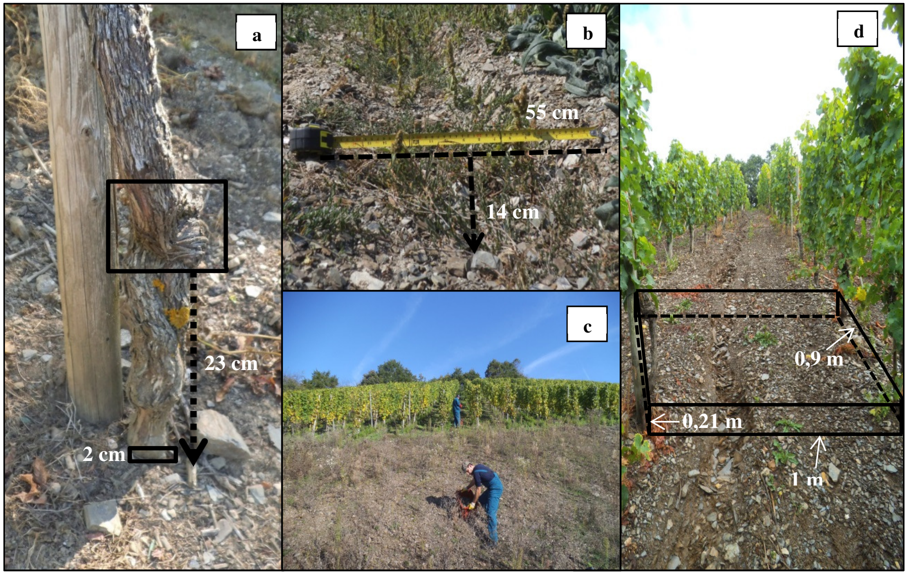


**Figure 3.** Monitoring of botanic marks and rills. **(a)** Example of measured distance between the botanic mark and the actual topsoil (with 2 cm of the initial planting). **(b)** Weekly geometrical rill monitoring: width and depth. **(c)** Vintage: vine workers use rills to ascend or descend the vineyards. **(d)** Imaginary polygon to calculate the soil loss with botanic marks.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

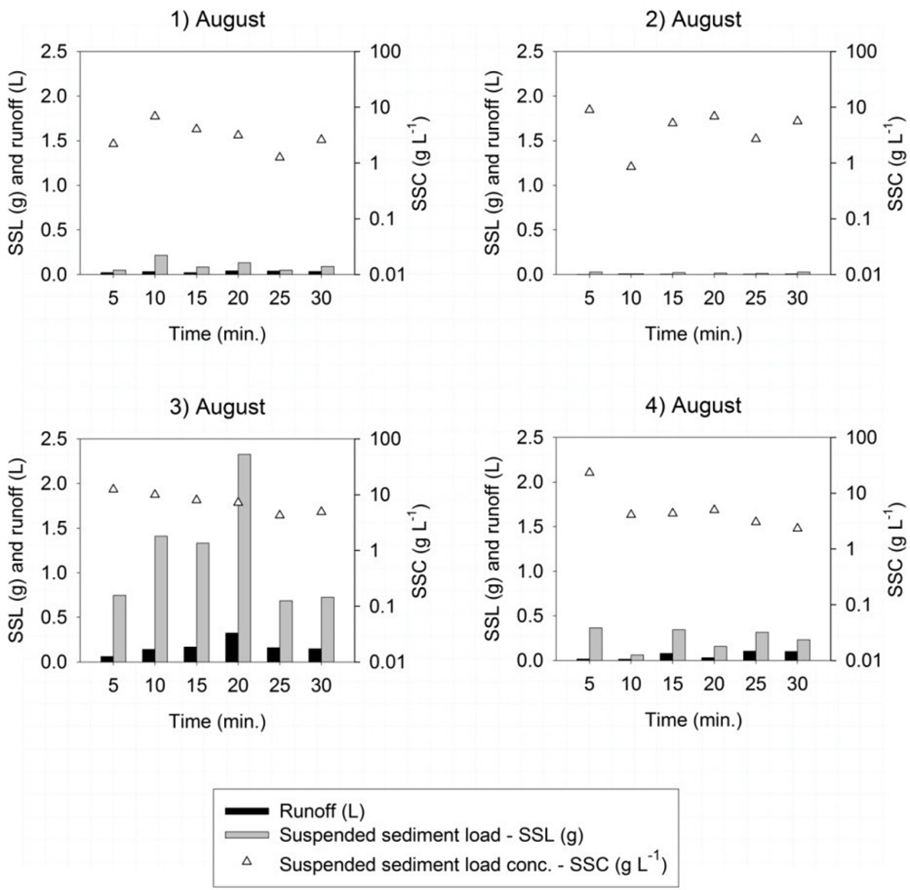


**Figure 4.** Relationships among variables: surface flow, suspension and sediment concentration.





SED
7, 259–299, 2015

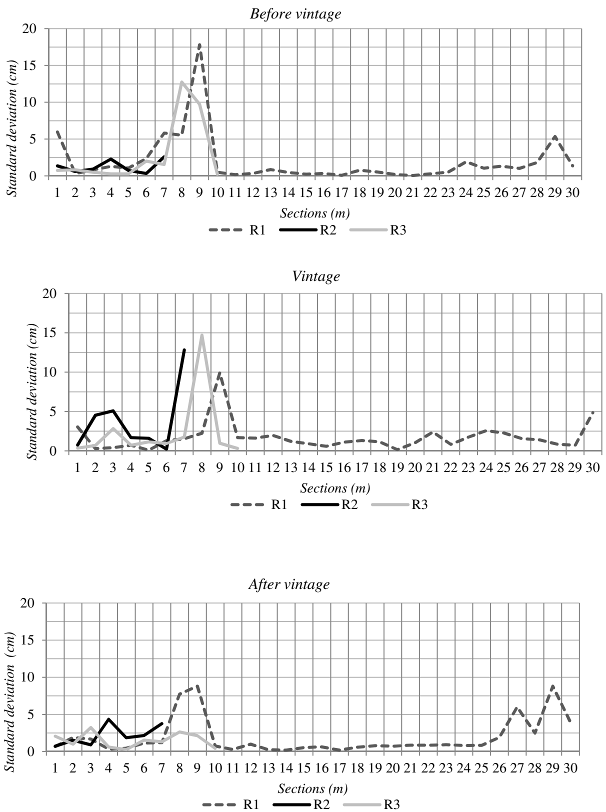


**Figure 5.** Temporal and spatial development of the monitored rills (R1, R2 and R3).





SED
7, 259–299, 2015

SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.



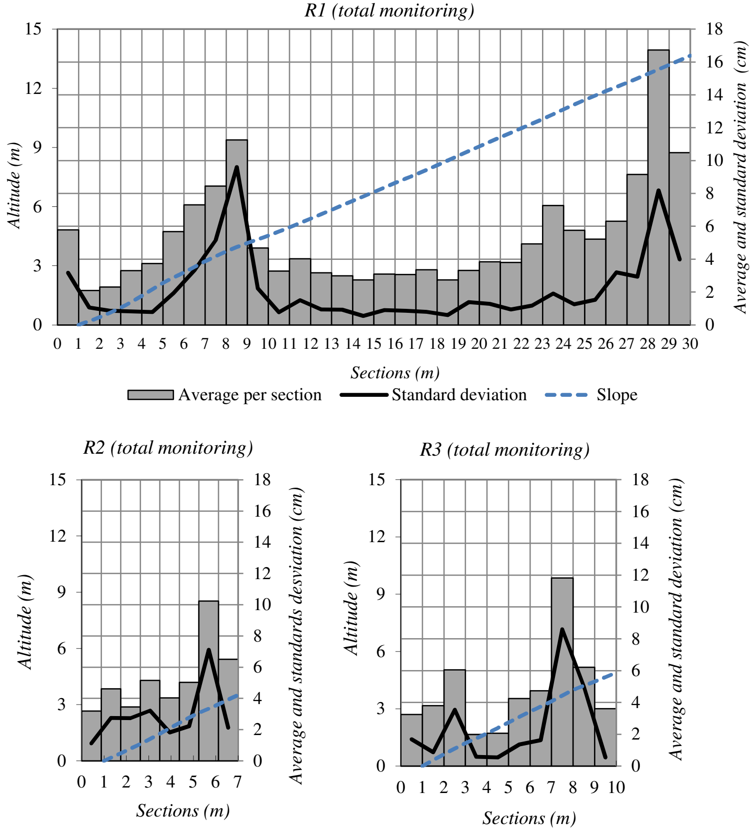


**Figure 6.** Geometrical channel cross-section developments of the rills during the total monitoring period (R1, R2 and R3).

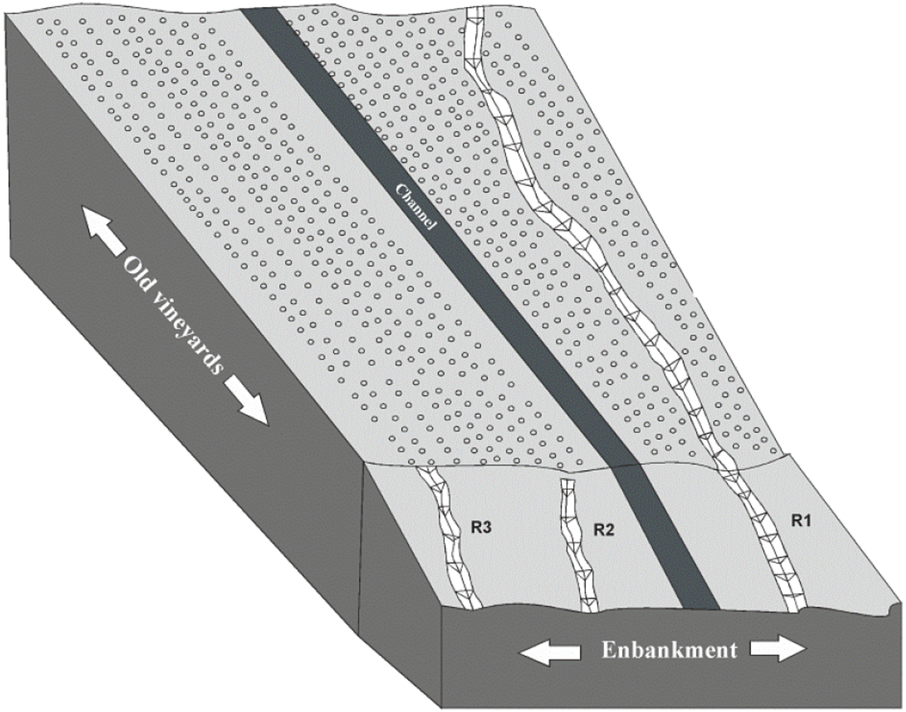


**Figure 7.** Diagram of the embankment with the rills on the old vineyards.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◂◂ ▸▸
◂ ▸
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

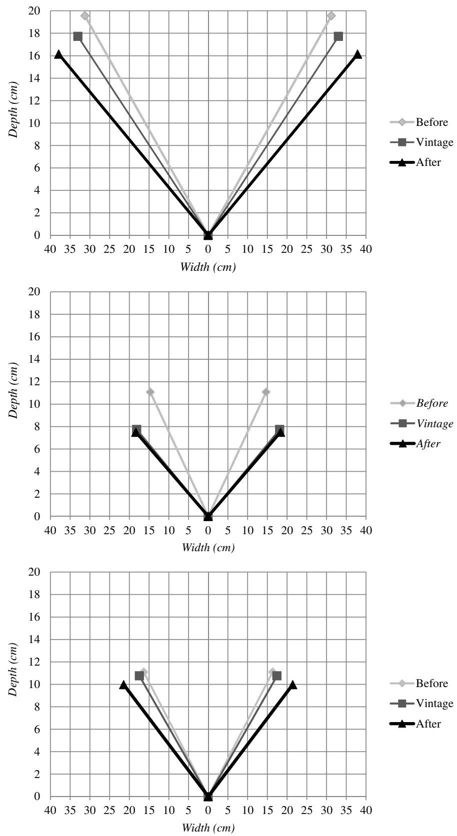


**Figure 8.** Geometrical channel cross-section averages of the rills during the total monitoring period (R1, R2 and R3) on the old vineyards.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

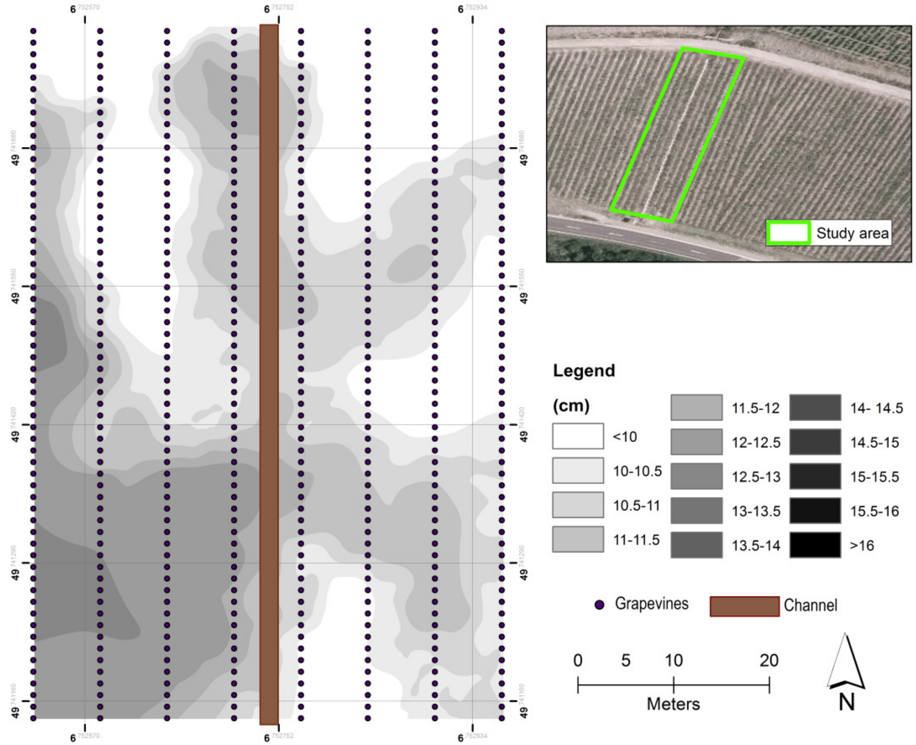


**Figure 9.** Soil level map in the young vineyard.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.

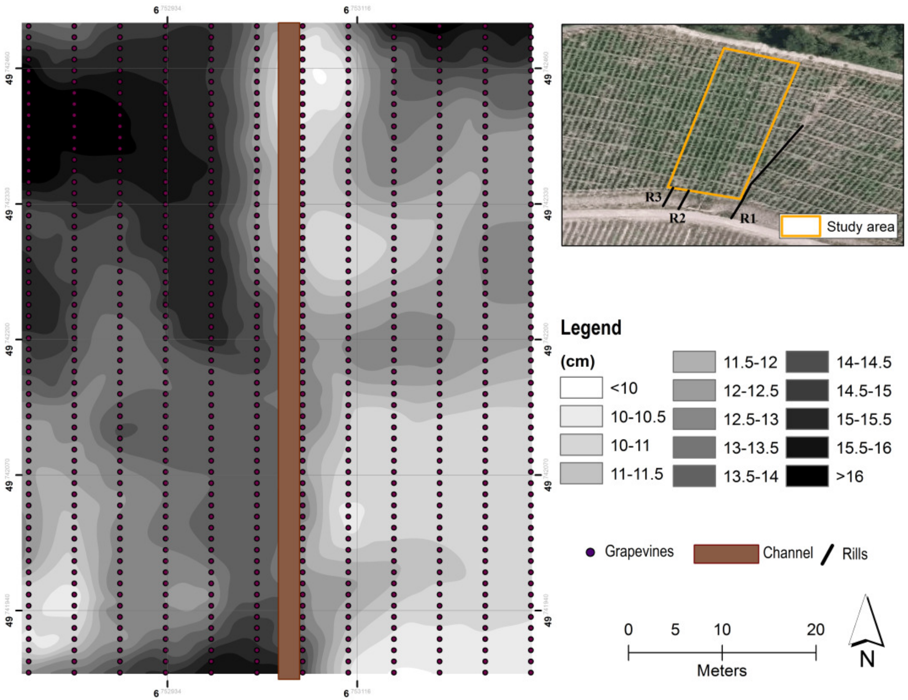


**Figure 10.** Soil level map in the old vineyard.





SED
7, 259–299, 2015

Rainfall and human activity impacts on soil losses and rill erosion in vineyards

J. Rodrigo Comino et al.