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 conditioned eco-geomorphological systems by human activity in Germany. The vineyards of the Ruwer Valley (Germany) are 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 deteriorate 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 chosen vineyards in Germany, during the different 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 planned on the two experimental plots in the village of Waldrach (Trier, region of Rhineland-Palatinate).
High infiltration rates (near 100%) and subsurface flow was detected by rainfall simulations performed at different times of the year. 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 concentrated during a short period of time. Finally, two maps of soil loss were generated, indicated by botanic marks on the graft union of the vines. 62.5 t ha^{-1} yr^{-1}soil loss was registered on the experimental plots of the new vineyards (two years), while 3.4 t ha^{-1} yr^{-1} on the old one (35 years).

1. Introduction

Traditionally vineyards are among eco-geomorphological systems mostly conditioned 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 anthropic environments with steep slopes, with bare soil cover and unsustainable land management activities (Martínez-Casasnovas et al., 2003; Paroissien et al., 2010).
On steep slopes in the European viticulture, terracing was the dominant correcting measure (Petit et al., 2012). However, the erosive processes affect with high 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 and anthropic erosion (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

Comentario [RCJ1]: This sentence has been improved higher after heavy and concentrated 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 specific study areas, erosion rates are very variable: Martínez-Casasnovas and Poch (1998) and Martínez Casasnovas et al. (2002) respectively 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) validated 30 t ha^{-1} yr^{-1} in France.

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 of soil loss rates from German vineyards reflected several differences, from 0.2 t ha^{-1} yr^{-1} (Richter, 1991) to 151 t ha^{-1} yr^{-1} (Emde, 1992).

Comentario [RCJ2]: This sentence has been improved

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 by the researchers of this department (Richter and Negendank, 1977; Richter, 1975, 1980a, 1980b, 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 constitute 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). This dynamic was significantly increased by the intensification of production and harmful tilling of the soil, which led 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, the presence of gullies and rills, soil compaction and alteration of the local biochemical cycle was 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) on 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 natural or anthropic rills and gullies (Poesen et al., 1998) or modern technics, like rainfall simulation. Small portable rainfall simulators, designed by Cerdà et al. (1997) or the innovations by Ries et al. (2009; 2013a; 2013b) 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, 2013b).

Comentario [RCJ3]: The bibliography about small portable rainfall simulators has been changed.

In practice, almost all manifestations of erosion forms in the vineyards have 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).
The purpose of this study is to characterize the soil erosion process of vineyards in the Ruwer Valley (Germany). The objectives are: i) to determinate the 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 (2 years) and ancient (35 years) vine cultivation, with the results of other locations with similar geomorphological characteristics. Finally, 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. The Ruwer Valley descends from a plateau formed at the Hünsrück Mountains, from about 500 m.a.s.l. in the south to approximately 200 m.a.s.l. in the north (Richter, 1980b).
Two types of vineyards were studied: i) old (cultivated more than 35 years); ii) young (planted less than a year ago). Both have the same lithological characteristics. 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) the presence of grass cover along the inter-rows and below grapevines (between 10-35 cm height); iii) the use of vine training systems to find equilibrium between leaves and the graft, to maximize photosynthesis and sugar creation, using all of the useful space possible along difficult steep slopes for tilling (between 23 and 36º).
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 a complete climatic station in the study area, values of rainfall and temperature (all with more than 30 years of data) must be extrapolated. Peripheral climatical 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 German Meteorological Service (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 per month). The lowest monthly precipitation is observed between February-April (50-60 mm per month). Annual average temperature is 9.3ºC, with average maximum values in June, July and August (16.2-17.6ºC), and minimum values along January and December (1.5-2.3ºC).

2.2. Soil analysis

Comentario [RCJ4]: All information about soil analysis (methods, table 1, bibliography...) has been improved and changed.

The soil samples were collected from four different positions on a space with no more than 0.5 m^2 and with different depths: 0-5 and >5 cm (maximum to 15-25 cm). Along two 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 they were taken in order to determine the soil properties, as grain size (<2 mm and >2 mm), pH, total organic carbon (TOC) and inorganic carbon (TIC) content by ignition (550º C and 1050º C respectively in muffle furnace). Saturation and absorption capacity was measured with a simplification of the "Counting the Number of Drop-Impact method" and by Emerson (1967), Imeson and Vis (1984) and Herrick et al. (2001). Finally, bulk density using steel cylinder were calculated.

2.3. Description of rainfall and agricultural events during the monitoring

Climatic and agricultural actions (during the monitoring) were 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 agro-climatic stations of the German Meteorological Service (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 frequent during all the research period. The daily intensity in this period (September to December) was 2.2 mm d^{-1} and the days with rainfall were 4.6 days in each interval of this monitoring period (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 and rainfall erosivity respectively (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 agro-climatic 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, the 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 rainfall greater than 40 mm h^{-1} would have a little probability to happen. So the different reactions of the soil to extreme rainfall could be recorded. 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 flow control (Type KSK-1200HIG100, 0-125 L h^{-1}, Kobold Company) and a manometer (with a calibrated pressure of 0.2 bar) were applied. In each simulation (30 minutes), we were using intervals of 5 minutes to collect runoff.

Since October until November the same results were obtained: total infiltration. Therefore, the last one was carried out in December (2013) and to understand the reason of the 100% infiltration, the stoney A horizon was removed inside the metal ring. The main purposes were to: i) confirm the increased infiltration; 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 origins 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 rills were measured. The first rill (R1) was caused by the wheel tracks and it was nearly 30 meters long (30 sections), starting from the bottom of the embankment. The average inclination of the rill was 28º and had approximately a contributing catchment area of 600 m^2. The second (R2) and third (R3) rill were located on the embankments with steeper slopes (34º and 31.7º) and had smaller contributing catchment areas (19 m^2 and 25 m^2). R2 (near a wall and drainage channel) was 7 meter length (7 sections), and R3 around 10 meters (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 (Dingman, 2008; Quiquerez et al. 2008):

$$\mathrm{TSI} = \frac{W}{Y}$$

Where W represents the width and Y the depth (both in centimetres). Note, while the quotient is more elevated, the widening process of rills is faster than the deepening process. Furthermore, the standard deviation was added to distinguish when averages were obtained with equal or unequal values. Consequently, two types of analyses with the geometrical channel cross-section index (Dingman, 2008; Quiquerez et al. 2008) were elaborated. Inclination was measured with a clinometer.

Firstly, the total average values per section were used to detect the most vulnerable transects, which were mostly modified by geomorphological changes both temporally and spatially. The second calculation aimed 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 show the theoretical ancient topsoil (Brenot et al., 2008). This analysis aims at 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 and those were: 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 almost constant from 22 to 24º. 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. The 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 1x1 meter.

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 an estimation. The sides of the polygon were the distance between each vine-stock (0.9x1 m), while the height was the distance between the botanic marks on the graft union and the visible actual rootstock. Total soil loss ($t\ ha^{-1}$) was estimated with the erosion-deposition (ER) equation (Paroissien et al. 2010):

Comentario [RCJ5]: Information of calculation by Paroissien et al. (2010) was included.

$$ER = \frac{Vol\ x\ Ds}{St\ x\ Av}$$

The volume (*Vol*), the total area field (*St*), the age of the vines (*Av*) and the bulk density data (*Ds*) were applied. 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 cm and >5cm). At this level, this method also requires the assumption that the study area is absolutely even. However, due to the rills, footsteps and wheel tracks it is rough.

3. Results

3.1. Soil analysis

Comentario [RCJ6]: All conclusions and results about soil analysis (methods, table 1, bibliography...) has been improved and changed.

Laboratory analysis data (Table 1) show chemical and physical properties of the soils, which are relevant to introduce the context of the geomorphological processes. The old (>68%) and young (>70%) vineyards have the highest concentration of grain size larger than 2 mm, which could be classified as stony soils. The highest concentration of organic matter (10-13%) was noted on the surface horizon (0-5 cm) along the old vineyards and the upper embankment, according with the most elevate rates of bulk density (1.4 g cm^3). The young vineyards and the below embankment have lower organic matter (< 6%) and more fine sediment concentration (<31%). The most elevated point of saturation and water absorption capacity of the soil samples were calculated along the subsurface horizons (>5 cm). The results of K factor indicating the 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. Finally, *Cambisol leptic-humic* was classified using the methodology of FAO (2006, 2007, 2014).

3.2. Rainfall events and land management during the study period

Soil surface characteristics, 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 the 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) and therefore rills appeared. This dynamic was observed at areas without vegetation cover or without cultivation (e.g. embankments).

After vintage the number of footsteps was decreased, 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 season 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 (Figure 4). During the other simulations 100% infiltration rate was observed.

For the four simulations of August, runoff and sediment suspension data appeared. The maximum runoff coefficient and suspended sediment load 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 minutes), 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 (October-November), 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 meters below the simulator was excavated (Fig. 2) in order to observe the intensity and direction of a possible subsurface-flow. From the beginning of the simulation, this hydrodynamic behaviour of total infiltration 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 behavior 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 for all rills: i) between 0-1 and 1-2 meters (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 meters fracture appeared in the slope as a micro-terraces (between 32º to 36º of slope), in which small slide scars by the soil movements were noticed below the A horizon; iii) along 7^{th} and 9^{th} meter at the top of the embankment, where the vines grapes were cultivated (the slopes were 30º to 23º); iv) only for R1 (originated by wheel tracks), it was noted an increase of the values of geometrical cross-section index from 26-27 metres and a maintaining of the gradient (27-28º). In this section, in contrast to deepening process weeding was favoured, especially during the vintage. Moreover, average values (Fig. 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 meters elevated data were observed (5.5±2.9 cm), but from here the values were descending (5.3±1.8 cm). Finally, the highest parameters were measured from 27 meters (10.7±4.6 cm), during the weeding processes (confluence of two or more rills).

Comentario [RCJ7]: An explantion about figures 7 and 8 was included.

3.5. Soil loss level maps

Fig. 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 table 5.
At each side of the channel and 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 increased near the channel in contact with the embankment on the left side (for the young grapevines 134.1 t ha^{-1} and 124.3 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 two years 116 t ha^{-1} and in 35 years 113 t ha^{-1}).
In two years of cultivation very high total soil loss was calculated (125 t ha^{-1} and 62.5 t ha^{-1} yr^{-1}). However, for the old vineyards (35 years), 118.7 t ha^{-1} erosion rates with an

Comentario [RCJ8]: This paragraph was rewritten.

annual rate of 3.4 t ha^{-1} yr^{-1} was calculated. Again, on the left side losses were higher than on the right side (3.6 and 3.2 t ha^{-1} yr^{-1}).

4. Conclusions and discussion

Comentario [RCJ9]: More ideas about conclusions and discusions were included (soil analysis, organic matter, erosion-deposition equation by Paroissien et al -2010-, soil tilling…).

Due to the stony soil surface (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%) were observed. During this study, applying different tools and experiments on the soil, was observed: i) subsurface processes, such as micro-piping or creeping ii) concrete pedological conditions, like variations between agricultural seasons or geomorphological instability after soil tilling.

Firstly, the highest organic matter content and bulk density were noted in the old vineyards, which could explain a lower sediment transport or soil movements across the hillslope than at the young vineyards and the embankments. On the other hand, the most saturation and absorption capacity rates were located from 5 cm depth. Subsurface flow dynamics could be analyzed, maybe according a high porosity rates due to these stony soils.

Secondly, spatial and temporal geometrical evolutions of rills were monitored with the geometrical channel cross-section index before, during and after the agricultural activities (vintage) in the study area. Accordingly soils had three different responses in the three different situations. The highest variability (in width and depth) of the rills was observed on the embankment close to the contention wall and drainage channel. Due to the soil tilling (land removal), no plants with their roots holding the soil and the uncorrected located wall, the development of the rills was increased. 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 and the erosion-deposition (ER) equation (Paroissien et al. 2010). The instructions of Brenot et al. (2008), Casalí et al. (2009) and Paroissien et al. (2010) was followed to measure the difference 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 118.7 t ha^{-1} soil loss was calculated on the old vineyard, which means 3.4 t ha^{-1} yr^{-1}. Respectively on the young vineyard 125 t ha^{-1}, which supposes 62.5 t ha^{-1} yr^{-1}, were measured. During the first years of plantation very high rates of soil losses were observed. However, the next years the sediment transport descends considerably, possibly due to: i) the soil tillage against the erosion is increased; ii) the structural stability of soils is improving continuously since the plantation (organic matter, bulk density, absorption capacity…). Although it might be asked how much money could be saved by the vine-growers, applying before directly correct land management measures on the hillslopes.

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).

Finally, the erosion rates could be compared with other studies about vineyards in the Mosel Valley, Germany and Europe by different authors (Table 6). The problem is nowadays relevant.

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 similar to the erosion rates of the old vineyards of this paper (3.4 t ha^{-1} yr^{-1}) 0.2-6.6 and 6.47 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 t ha^{-1} yr^{-1}), with extrapolations from different works.

Only Emde (1992) with USLE inferred a rate over 150 t ha^{-1} yr^{-1}, which is approximated to the soil erosion of the young grapevines (62.5 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 compared to other land uses (forest, grassland, shrubs or regeneration).

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Table 1. Soil analysis of the study area

Soil samples	>2 mm (%Total)	<2 mm (%Total)	pH	TOC (%)[a]	TIC (%)[b]	Saturation (%)[c]	Absorption capacity (%)[d]	Bulk density (gr/cm3)
Old grapevines (0-5 cm)	68.18	31.82	6.6	10.7	1.5	11.3	12.7	1.4
Old grapevines (5-15 cm)	66.19	33.81	6.6	6.5	1.5	9.8	10.9	1.4
Upper embankment (0-5 cm)	61.45	38.55	6.7	13.7	1.5	10.1	11.2	1.4
Upper embankment (5-15 cm)	58.25	41.75	6.3	6.6	2.2	11.2	12.6	1.4
Below embankment (0-5 cm)	61.82	38.18	6.4	5.7	1.3	9.1	10	1.3
Below embankment (5-15 cm)	68.85	31.15	6.7	5.7	1.4	11.8	13.4	1.4
Young grapevines (0-5 cm)	70.17	29.83	6.6	4.1	2.3	11	12.5	1.1
Young grapevines (5-15 cm)	70.68	29.32	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) x 100; d) Absorption capacity (%) = (Weighted of saturated aggregate – Initial weighted) / Initial weighted) x 100.

Comentario [RCJ10]: More information abou the methods and conclusions was included along the text (2.2., 3.1., 4).

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

Monitoring phase	Date	Rainfall (mm)*	Days with rain	Intensity (mm d^{-1})	Activities
Before vintage	24.09.2013	22.98	6.6	3.3	Leaves of the grapevines were cut to improve the absorption of the sunlight and appearance of footsteps.
	1.10.2013	10.34	4.3	1.5	
	8.10.2013	1.25	2.5	0.2	
Vintage	15.10.2013	22.78	3.3	3.3	Several footsteps marks were situated from the sections 0-1 to 8-9 meters. A lot of grapes and leaves stayed on the surface.
	22.10.2013	26.63	4.1	3.8	
	29.10.2013	8.78	4.9	1.3	
After vintage	6.11.2013	51.40	5.9	7.3	Several footsteps modified R2. Increasing of lateral enlargement (no deepening).
	12.11.2013	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).
	19.11.2013	10.34	6.3	1.5	The soil was cleaned of leaves and branches. Footsteps developed to new rills by the rainfall.
	26.11.2013	1.95	4.0	0.3	Each morning soil freeze appeared. After midday it was almost dry, but not the subsurface horizons.
	03.12.2013	7.96	4.8	1.1	
	10.12.2013	3.24	4.3	0.5	Footsteps marks were visible only from the sections 0-1 to 1-2. Rills stayed without remarkable changes.

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

Table 3. Return period of rainfall events per year.

Rainfall depth (mm)	% probability of return period (d^{-1} yr^{-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

Table 4. Rainfall simulation parameters

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

* = Rainfall simulation without A horizon.

Table 5. Volume estimations of soil loss in young and old vineyards

Comentario [RCJ11]: The table was joined in only one.

	Parameters	m^3 ha^{-1}	t ha^{-1}*	t ha^{-1} yr^{-1}
Young vineyards (2 years)	Total soil loss	4.7	125	62.5
	Total on the left side	5.1	134.1	67.1
	Total on the right side	4.4	116	58
Old vineyards (35 years)	Total soil loss	5.5	118.7	3.4
	Total on the left side	5.8	124.3	3.6
	Total on the right side	5.2	113	3.2

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

Table 6. 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 0.67 0.87 1.2 6.47	Regeneration Forest Shrubs Grassland Vineyards
Auerswald et al. (2009)	Germany	Extrapolations and R factor of USLE (Universal Soil Loss Equation)	5.7 0.5 0.2 5.2	Annual arable land Grassland Forest Vineyards
Cerdan et al. (2006, 2010)	Europe	Extrapolations from other works	12.2	Vineyards
This study	Waldrach (Mosel Valley)	Botanic marks	3.4-62.5*	Vineyards

* = 3.4 t ha^{-1} yr^{-1} on the old vineyards (average in 35 years) and 62.5 t ha^{-1} yr^{-1} for the other area with young grapevines (since 2012).

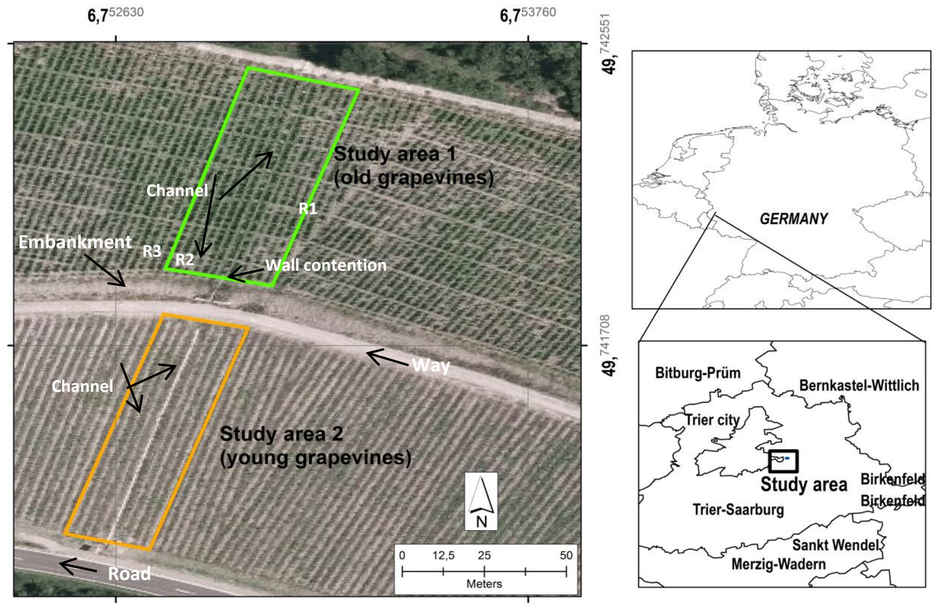


Figure 1. Study area in Waldrach (Ruwer Valley, Germany).

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 x 0.5m) with the sediment collector. d) Situation of simulator ring. e) Concurrently rainfall simulation f) Subsurface flow during the experiment.

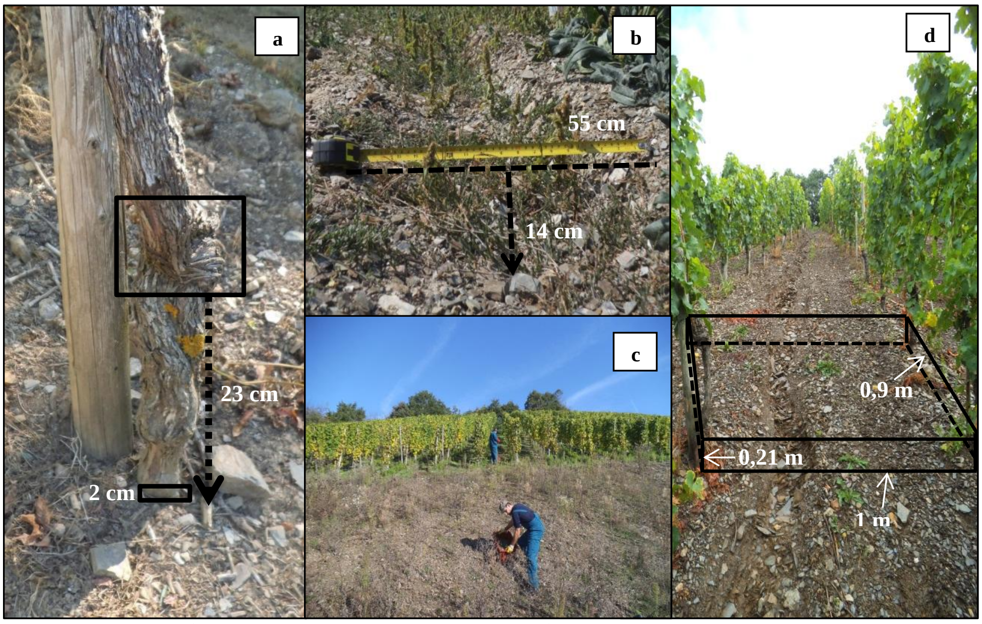


Fig. 3. Monitoring of botanic marks and rills. a) Example of measured distance between the botanic mark and the actual topsoil (with 2 cm of the initial planting); b) Weekly geometrical rill monitoring: width and depth; c) Vintage: vine workers use rills to ascend or descend the vineyards; d) Imaginary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

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

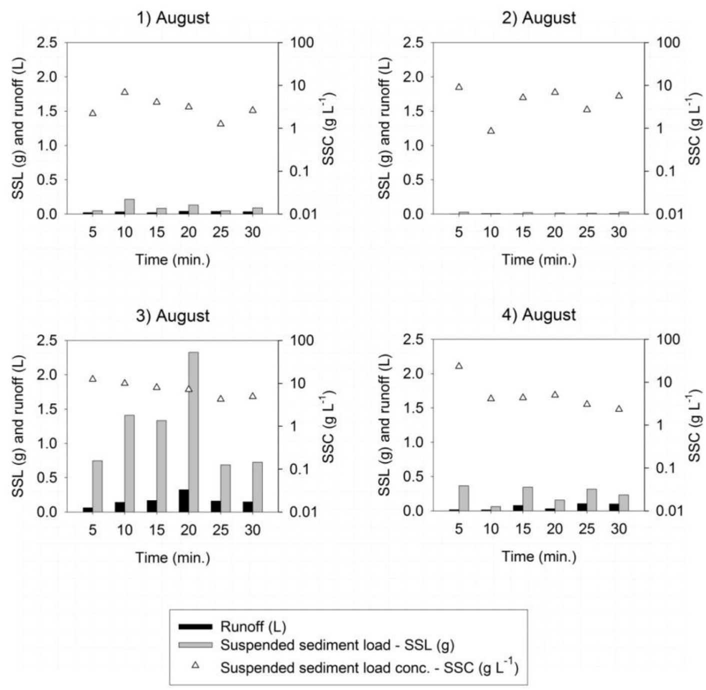


Figure 5. Temporal and spatial development of the monitored rills (R1, R2 and R3)

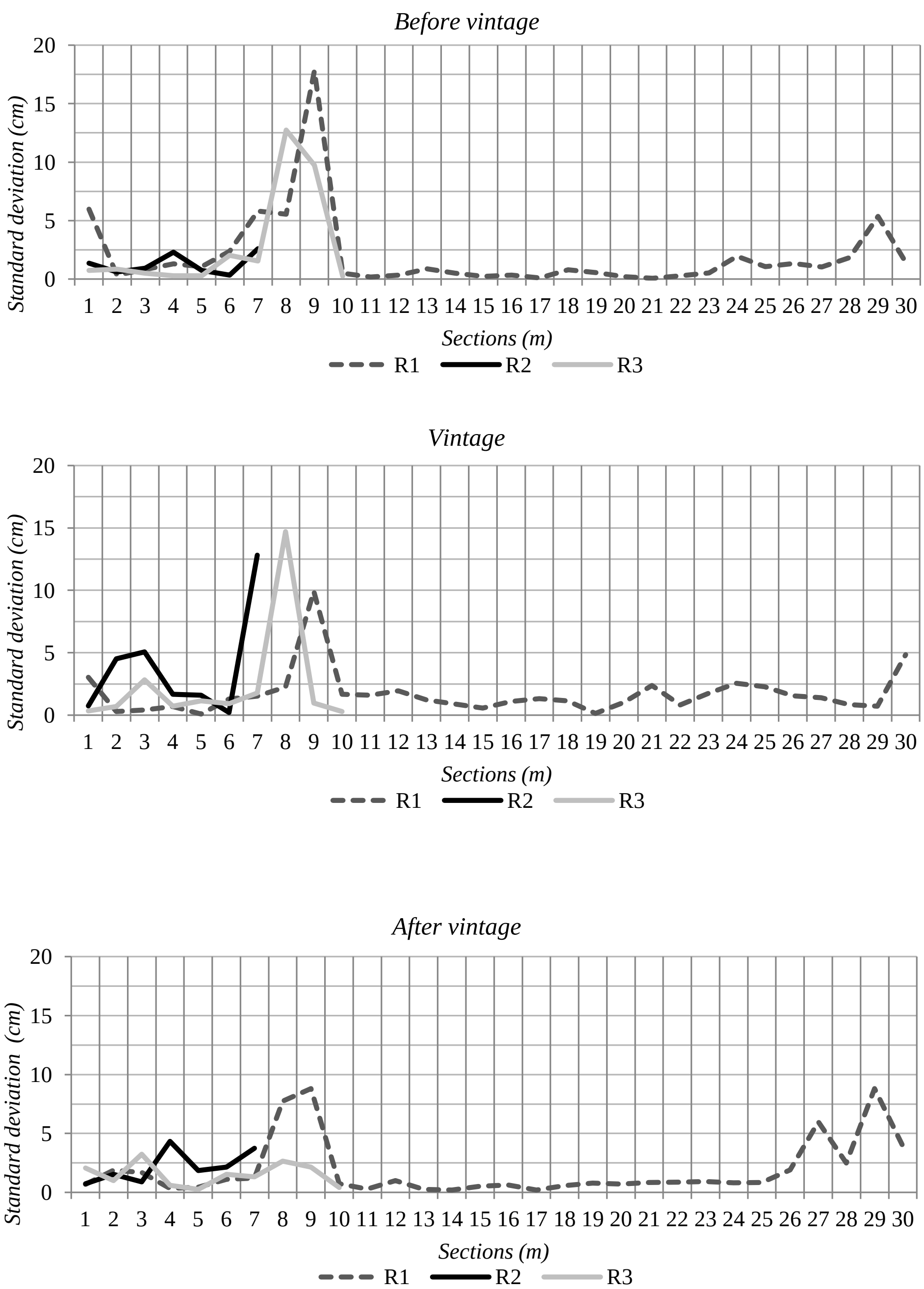
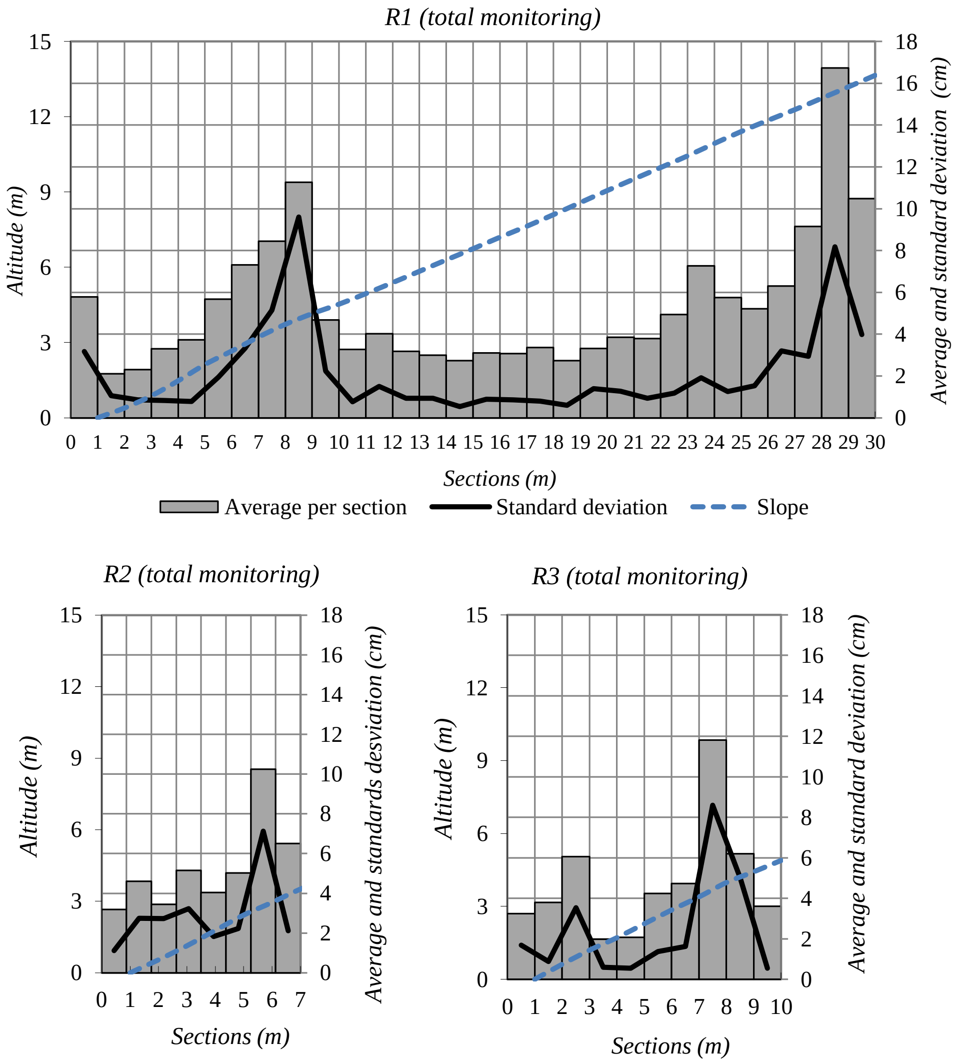


Figure 6. Geometrical channel cross-section developments of the rills during the whole monitoring period (R1, R2 and R3)



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

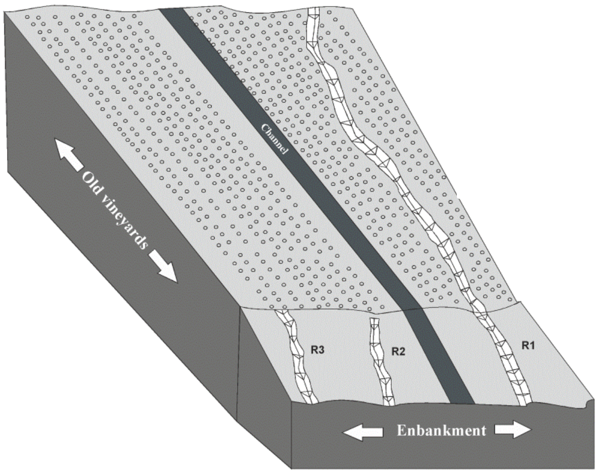


Figure 8. Geometrical channel cross-section averages of the rills during the total monitoring period (R1, R2 and R3) on the old vineyards

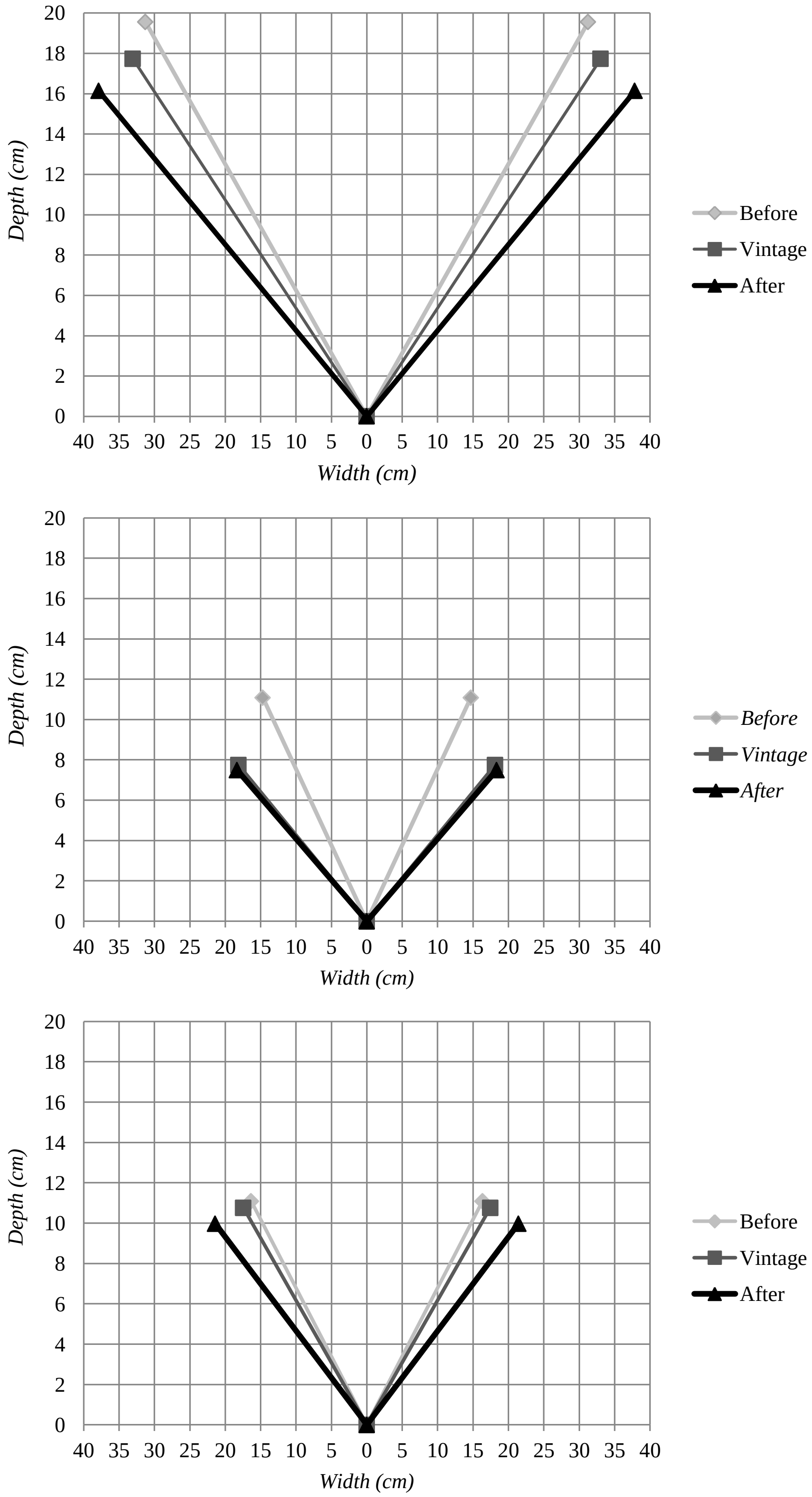


Figure 9. Soil level map of the young vineyard

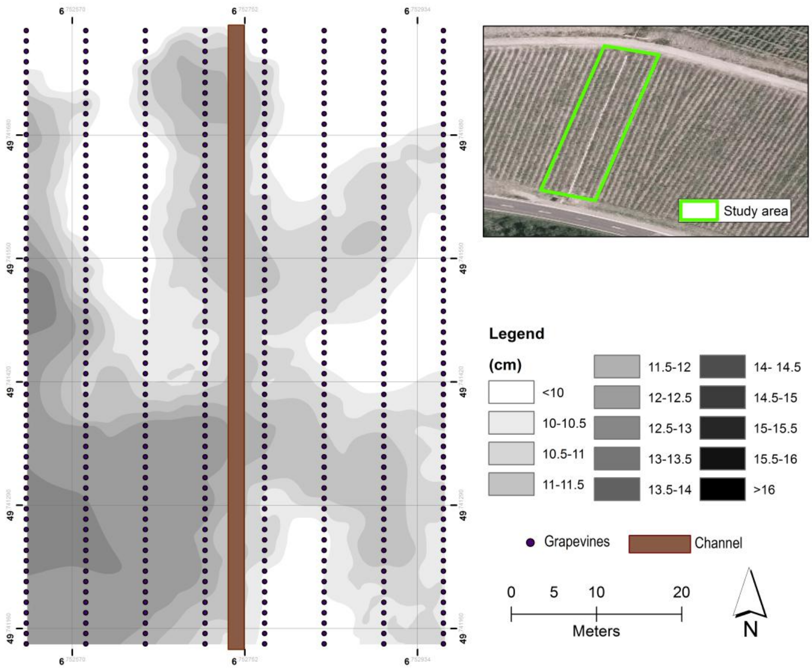


Figure 10. Soil level map of the old vineyard