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Assessing environmental changes in abandoned German vineyards. Understanding key issues for restoration management plans

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Abstract

Land degradation in vineyards is a big concern which should be considered by farmers, enterprises and policymakers. Due to intense tillage, the use of herbicides and heavy machinery, vine plantations are registering a decrease in soil fertility and, subsequently, in productivity. Recently, farmers have decided to abandon the vineyards, but any restoration planning is being carried out to recover biodiversity or to reduce soil and water losses. Nowadays, there is no information about environmental changes after the abandonment in terms of possible soil property changes and erosion in Central European vineyards such as in Germany. Therefore, the main aims of this preliminary study were to compare: i) soil properties and soil profiles of one cultivated vineyard and an abandoned one; and, ii) to assess the activation of soil erosion processes using a small portable rainfall simulator. Our results showed that the vineyard registered several differences in soil properties among slope positions and soil profile characteristics due to tillage and trampling effects, showing clear marks of compaction and soil detachment in the lower parts. Also, in this cultivated field, higher means and maxima of soil losses (g m^{-2}) and sediment concentration (g l^{-1}) values than in the abandoned plot were quantified, being the main driving factors the vegetation cover and the inclination. On the other hand, in the abandoned vine plantation, a rapid homogenization of soil profiles and soil properties were found along the hillslope, where a deeper organic horizon was consistently developed above a compacted and rocky horizon, which was generated during the cultivation phase. Due to the high compaction due to the machinery cultivation and the difficulties for the roots to make deep into the soil, the infiltration defaulted and the amount of runoff and runoff coefficient were higher in the abandoned plots than in the cultivated ones.

Keywords: Soil erosion, German vineyards, abandonment, rainfall simulation, soil profile

Introduction

Soil erosion is a big concern for humankind because soils provide indispensable sources and goods for living creatures and human health (Smith, P. *et al.* 2015). However, negative human impacts on soils such as the intensification of the agricultural practices are generating a drastic decrease in soil fertility and quality (Szalai, Z. *et al.* 2016). Therefore, to solve these kinds of problems and achieve the best solutions, the scientific community and the policymakers should collaborate with the stakeholders, actively. In this way, physical geographers have to play an important role in developing research methods and tools which are able to design sustainable land plans and feasible measures.

Techniques such as modeling (Samani, A.N. *et al.* 2016; Balázs, B. *et al.* 2018), erosion plots (Kinnell, P.I.A. 2016) or isotopic markers (Bihari, Á. and Dezső, Z. 2008; Novara,

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A. *et al.* 2016; Jakab, G. *et al*. 2018) are the most common methods applied to quantify soil erosion. However, to make reproducible and comparable results of water and soil losses, rainfall simulations can be also considered a valuable tool (Iserloh, T. *et al.* 2012; Szabó, J. *et al.* 2015).

In vineyards, the use of rainfall simulations to study initial soil erosion processes has increased because they are one of the most degraded landscapes. Rodrigo-Comino, J. *et al.* (2016a, b) qualitatively assessed different viticultural areas across Europe where distinct rainfall simulations showed high soil and water losses in Campo Real (Madrid, Spain), Champagne (France), the Pènedes (Lleida, Spain) or Ruwer-Mosel valley (Trier, Germany). Also, the use of small portable rainfall simulators has been applied to investigate different specific environmental characteristics in vineyards or erosion control measures (Blavet, D. *et al.* 2009; Morvan, X. *et al.* 2014). However, there is another process that is also affecting the rest of the European vineyards and which has not sufficiently been investigated: land abandonment (Lasanta, T. *et al.* 2015).

Vineyards´ soils are suffering from a high degradation as a consequence of intense tillage, the use of herbicides and heavy machinery, registering a decrease in soil fertility and, subsequently, also in productivity (Camps, J.O. and Ramos, M.C. 2012; García-Díaz, A. *et al.* 2017). Therefore, when the most fertile horizon is eliminated, vine growers decide to abandon the whole plantation. Also, as a consequence of the climate change, low lands are being abandoned, and hillslopes on the higher heights are being planted (Arnaez, J. *et al.* 2006; Galilea Salvador, I. *et al.* 2015). Recently, using rainfall simulations experiments (Martínez-Hernández, C. *et al.* 2017), it was observed that areas where there was no vegetation recovery at all, such as in almond trees, soil loss and runoff were higher than in the cultivated areas.

In Germany, the viticultural sector is reporting high benefits for wine producers and new planting is taking place (O.I.V. 2017). However, when a plantation is not productive or the next generation of farmers do not show any interest in vineyards, the abandonment process begins and a restoration plan should be conducted. Vegetation and biodiversity recoveries show positive benefits for both environment and humankind (Bienes, R. *et al.* 2016), but no incentives to carry out some kind of measures default this action.

In this way, there is no information about which environmental problems after the abandonment (e.g. soil erosion) in Central European vineyards such as in Germany could occur. We only found some precedents, for example in a study carried out in Eastern countries such as Hungary in the traditional Tokaj viticulture area, where the vegetation transformation and toposequences of the carbon storage after the abandonment and its influence on soil changes were studied (Novák, T.J. *et al.* 2014).

Therefore, the main goal of this preliminary research is to compare soils properties and initial soil erosion processes in a cultivated vineyard with an abandoned one. We pretend to show the main differences and transformations after the abandonment process in the same vineyard. To achieve this goal, soil profiles, soil analysis, and rainfall simulations were used.

Materials and methods

Study area

The localization of the two studied paired-plots can be observed in *Figure 1*. The selected vineyard and abandoned one are situated in the little village of Waldrach in the Ruwer-Moselle valley (Rhineland-Palatinate), Germany. The average elevation ranges from 200 m to 400 m a.s.l. and all are located on Devonian grauwackes, slates, and quartzites, which are in contact with Pleistocene fine materials transported by the Ruwer river, an affluent of Moselle river (Richter, G. 1979). The vine plantation is composed of 40-years old plants and was cultivated in the summit of a

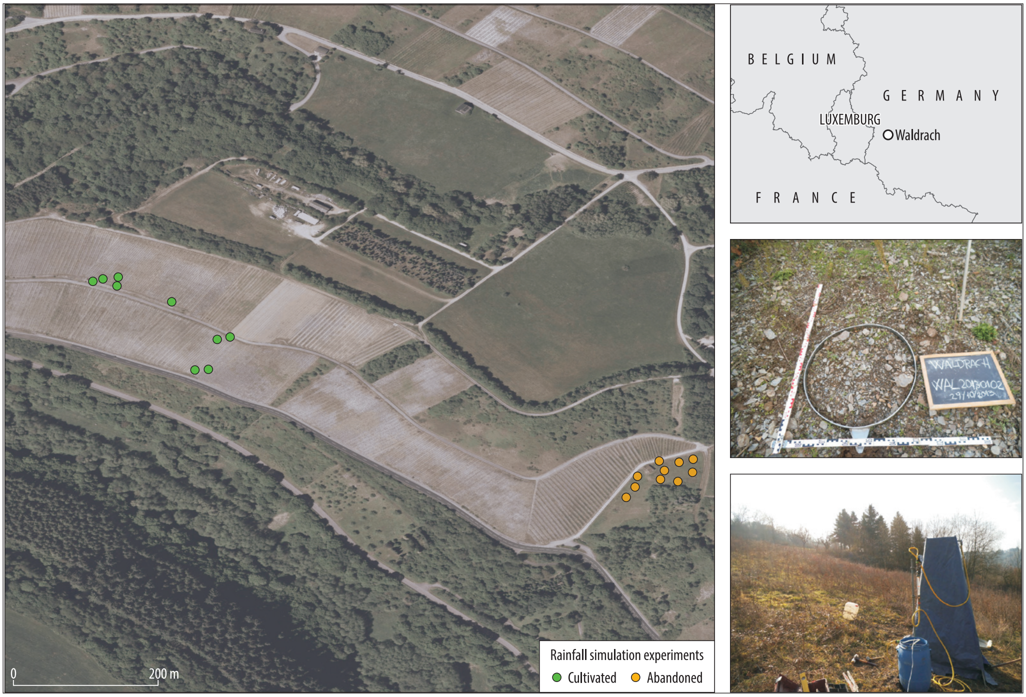

Fig. 1. Study area and rainfall simulation localization of the experiments

hillslope. On the other hand, the abandoned study plot (cultivated during 1970 with similar tillage practices to the recently cultivated one) was abandoned during 1990. In general, the hillslopes are exposed to SW direction and mean inclinations reach maximum values of 30º, although the studied abandoned plot shows more gentle angles (15–25°). Annual total average rainfall is about 765 mm and mean annual temperatures approximately 9 °C (Rodrigo-Comino, J. *et al.* 2015).

The grape variety is Riesling and the main soil management practices are as follows: i) tilling with machinery before and after the vintage to 20 cm depth (beginning of spring, and autumn); ii) the use of vine training systems with a plantation framework of 90 x 140 cm; iii) a high amount of slate mulch to conserve soil temperature regime; and, iv) keeping soils bare as much as possible by applying pesticides and herbicides.

In both areas, on the embankments and inter-rows, rills, landslides, and ephemeral gullies as a consequence of soil erosion can be observed. The abandoned plot is cleaned from spontaneous vegetation once in the year to prevent the recolonization close to the roads and drainages as a part of maintenance practice.

Soil profile description and soil analysis

Soil samples were collected from three different slope positions (shoulder, backslope, and footslope), at two different depths (0–5 cm and 5–15 cm) in the rows and inter-row areas. All the samples were analysed with three replicates, being a total 36 samples and amounting to about 3–4 kg per soil sample. First, at all, soil samples were sieved (<2 mm) and basic soil properties were analysed in the laboratory: Texture, total organic carbon (TOC), Calcium carbonates (Ca), electrical conductivity (EC), pH-value and soil water content (SWC).

Texture (sand, silt, and clays) was analysed by a Coulter LS230 device, by combining different diffraction patterns of a light beam. Total organic carbon was measured by loss of ignition (LOI) and its weight difference under 430 °C (24 h) in a muffle furnace (Davies, B.E. 1974; Rosell, R.A. *et al.* 2001). Electrical conductivity (EC) was measured by a digital conductivity-meter and carbonates with a Bernard calcimeter. pH-value in distilled water (1:5 proportion) using a digital pH-meter was obtained. Soil water capacity content at field capacity and wilting point were calculated with a pressure plate extractor.

Finally, three soil profiles at different slope positions (coinciding with the soil sample places) were described to classify soil types, using the methodology designed by FAO-WRB (IUSS Working Group WRB 2006, 2014).

Rainfall simulations

Nine rainfall simulations were carried out in the cultivated vineyard and fourteen in the abandoned one to compare soil loss, runoff, runoff coefficient, sediment concentration and infiltration. In *Figure 1*, the localisation of the experiments was mapped. We used a small nozzle-type rainfall simulator modified by Ries, J.B. *et al.* (2009). This device is characterized by i) a square metal frame (0.45 m x 0.45 m) with a Lechler 460 608 nozzle; ii) four telescopic aluminium legs in order to situate the nozzle two meters above the plot; iii) the aluminium linkage is covered by a rubber tarpaulin to eliminate wind interferences; iv) a circular test plot of 0.28 m^2 with a V-shaped outlet, which is put at the deepest point at surface level to collect the water and soil losses; v) a flow control and a 12 V low-pressure bilge pump that controls and make reproducible the simulated rainfall. The rainfall simulator was calibrated by Iserloh, T. *et al.* (2012) for a rainfall intensity of 40 mm h^{-1}.

Each experiment had a total duration of 30 minutes and was conducted in a randomized block at different slope positions. In five minutes′ intervals (six intervals in total), water and sediments were collected in plastic bottles, which were also changed at the beginning of a new interval. Prior starting the experiments, vegetation and rock fragment covers were perceptively quantified by taking the opinion of three experts, soil roughness was assessed with the chain method (Saleh, A. 1993), slope inclination was measured with a digital clinometer and antecedent soil moisture was calculated by taking a soil sample close to the ring plot and drying at air conditions in the laboratory. The collected water with sediments in each bottle was filtrated with circular fine-meshed filter papers (Munktell©, Prod.-Nr. 3.104.185, less than 2 μm mesh-width) and, then, filters were dried to constant weight at 105 °C. After that, they were weighted for determining soil loss (g) and runoff (l) for each measured interval. Final results were presented in g m^{-2} and l m^{-2} in order to be comparable with other study areas. Also, sediment concentration (g l^{-1}) was obtained by dividing the amount of soil loss and runoff. Runoff and infiltration coefficients were also calculated using the total area of the plot and rainfall intensity in each interval.

Statistical analysis

Descriptive statistics in boxplot graphics and tables to identify averages, maximum, minimum, median and outlier values were depicted and summarized, respectively. To compare soil properties obtained from both paired-plots (cultivated and abandoned), a nonparametric test at $p > 0.05$ was performed after testing the data normality (Shaphiro-Wilk test) and equal variance (F-test). They did not show a normal distribution. We used a Tukey test, where significant differences at $p < 0.001$ level were considered.

Finally, to confirm which driving factor enhances soil erosion and makes a comparison between which environmental plot characteristic and erosion result shows possible interrelationships, a Spearman's rank correlation coefficient was conducted. SigmaPlot 12.0 (Systat Software Inc.) was the software used to carry out the statistical analysis.

Results and discussion

Soil analysis

Soil analysis results showed a higher proportion of coarse gravel (>2 mm) in the cultivated plots than in the abandoned one is registered. It is important to remark that in both plots more than 34 per cent of gravels were found. The rock fragment cover is a widely studied factor in vineyards (Rodrigo-Comino, J. *et al.* 2017) and in other crops or environments (Nyssen, J. *et al.* 2001; Jomaa, S. *et al.* 2012), because it shows a strong correlation with runoff and soil losses when it is embedded into the soil (Poesen, J.W. *et al.* 1998). If not, rock fragment cover uses to enhance infiltration (Zavala, L.M. *et al.* 2010) and biodiversity activity (Certini, G. *et al.* 2004). Moreover, both soils show a silty texture, but after the abandonment, a higher content of clays and fine silts can be registered. This process was also registered in other abandoned areas with schists as parent material (Martínez-Hernández, C. *et al.* 2017), although it appears more frequent in calcareous rocks, where a selective removal of fine particles occurs (Romero Díaz, A. *et al.* 2011), also affecting other soil properties such as water retention capacity and pH (Lesschen, J.P. *et al.* 2008; Bienes, R. *et al.* 2016). In our study area, this process could also be recognized. After the abandonment, increases in water retention capacity at the wilting point and at field capacity are observed. Moreover, pH also decreases, showing a more acidic trend, which is also an ecological indicator of soil quality registered after each land use change (Khaledian, Y. *et al.* 2017; Pahlavan-Rad, M.R. and Akbarimoghaddam, A. 2018). Statistical analysis proved that soil texture, organic carbon, carbonate, soil water retention capacity and pH show a significant difference among cultivated and abandoned plots, confirming the changes in soil properties after the abandonment *(Table 1).*

Soil profile descriptions and qualitatively assessment

In *Figure 2* and *3*, soil profiles described at different slope positions also show differences among each other and after the abandonment process. In Suppl. Material, the description of all soil profiles is included to observe more in detail these differences.

As we can observe in the cultivated plot *(Figure 2)*, soil profiles in the shoulder and backslope positions are characterized by a thin organo-mineral soil horizon (nearly 2 cm deep) with high alteration induced by tillage and compaction. This horizon can be signed as Ap. Underneath, a tilled soil horizon, which could be considered as Ap_2, has deeper mineral soil horizons (B/C). The horizon boundaries in Ap and B/C are abrupt (2–5 cm) and nearly plane in the compacted layers, and irregular in the rocky layer. Soil structure grade ranges from moderate to weak, with prismatic and crumb forms. However, in the footslope, one unique horizon can be described which is characterized by clear marks of compaction. Moreover, the surface horizon is removed as a consequence of the depletion, which was also confirmed by Rodrigo-Comino, J. *et al.* (2016b) using the stock unearthing method and topsoil level change maps. It is widely known in studies about connectivity processes that soil depth variations among slope positions can be linked to the fact of the mass movement processes, registering in the upper part erosion, in the middle erosion-deposition (transition) and, finally, in the lower part sedimentation (López-Vicente, M. *et. al.* 2015; Novara, A. *et al.* 2016; Rodrigo-Comino, J. *et al.* 2016a, b; Ben-Salem, N. *et al*. 2018). However, in tilled vineyards, the redistribution of materials (Follain, S. *et al.* 2012; Quiquerez, A. *et al.* 2014), tractor passes (Biddoccu, M. *et al.* 2017) and extreme

Table 1. Soil properties and differences among cultivated and abandoned plots

Plots		Soil particles >2 mm	Soil particles <2 mm	Sand	Silt	Clay	LOI	CaC	FC	WP	pH, H_2O	EC, dS m^{-1}
		in %										
Cultivated	x̄	37.7	62.3	44.9	45.5	9.6	4.7	0.7	24.4	10.3	7.1	0.2
	±	6.6	6.6	4.4	3.3	1.4	1.0	0.3	2.3	0.9	0.2	0.1
	Max	46.2	73.8	52.0	50.0	12.6	6.6	1.3	29.3	12.5	7.4	0.5
	Min	26.2	53.8	38.0	39.8	7.5	3.6	0.3	21.3	8.8	6.7	0.1
Abandoned	x̄	34.6	65.4	16.9	70.5	12.6	6.7	2.6	31.2	12.6	6.6	0.2
	±	17.9	17.9	7.1	4.3	3.3	1.6	0.7	4.0	2.4	0.7	0.1
	Max	65.7	93.2	33.5	80.3	20.4	9.5	5.0	37.2	16.7	7.9	0.4
	Min	6.8	34.3	2.1	59.5	7.0	3.9	2.2	25.4	8.8	6.0	0.1
Differences	p<	0.488					0.001			0.002	0.011	0.282

Notes: LOI = Los organic matter by ignition; CaC = Carbonate content; FC = Soil water content at the field point; WP = Soil water content at the wilting point; EC = Electrical conductivity.

rainfall events (Martínez-Casasnovas, J.A. *et al.* 2003; De Santisteban, L.M. *et al.* 2006) make difficult to predict topsoil level changes along the hillslope.

In the abandoned vine plantation *(Figure 3)*, soil profiles are characterized by 0 to 4 cm deep-rooted organic soil horizons (litter horizon O), where there are no rests of any Ap horizon and soil aggregates are similarly absent. The boundaries with underlying soil horizons are also abrupt. Underneath, we find a B/C horizon characterized by tilled and compacted mineral features. High rock fragment contents are noted in this layer with a weak soil structure characterized by prismatic and crumb forms of 20–50 mm size. Several authors confirmed that the recuperation of abandoned soils in semiarid and arid areas need long periods (Romero Díaz, A. *et al.* 2011; Kou, M. *et al.* 2016); however, in two decades we observe that Central European vineyards are able to generate a consistent A horizon relatively fast; although the compaction marks stay there yet.

Finally, these soils can be classified as *Leptic-Humic Regosols* according to the FAO/WRB soil classification (IUSS Working Group WRB, 2014).

Initial soil erosion processes

Rainfall simulation results can be observed in *Table 2* and *3*, where soil erosion results and environmental plot characteristics inside the ring plot are summarized, confirming high differences among plots. In *Figure 4*, mean, median, maximum, minimum values and outliers of measured soil erosion in both plots are depicted in box plots.

The most important differences inside the ring plots are found for vegetation cover and roughness, being higher in the abandoned plot than in the cultivated vineyard (97% vs 45%; 1.3 mm mm^{-1} vs 1.05 mm mm^{-1}). On the other hand, rock fragment covers and slope grades are higher in the cultivated vineyard than in the abandoned plot, reaching average values of 58, 28, 17 and 5 per cent, respectively.

Fig. 2. Soil profiles in the cultivated plot. – a = soil profile elaboration; b = a general perspective of the plot; c = shoulder; d = backslope; e = footslope

Fig. 3. Soil profiles in the abandoned plot. – a–e = For explanation see *Fig. 2.*

Table 2. Rainfall simulation results and environmental plot characteristics in the cultivated vineyard

ID	Runoff			Soil loss		SC, g l^{-1}	Slope	VC	RFc	ASM	Roughness, mm mm^{-1}
	l	l m^{2}	%	g	g m^{2}		%				
1	0.2	0.7	3.9	0.6	2.2	3.3	26.0	0.0	100.0	12.4	1.1
2	0.0	0.1	0.5	0.1	0.4	5.0	36.5	35.0	90.0	14.3	1.0
3	1.0	3.6	15.2	7.2	25.8	7.8	23.0	10.0	60.0	16.5	1.1
4	0.3	1.2	6.7	1.5	5.3	7.0	27.0	70.0	75.0	17.0	1.1
5	0.0	0.0	0.0	0.0	0.0	0.0	27.1	40.0	60.0	18.0	1.0
6	0.0	0.0	0.0	0.0	0.0	0.0	37.0	7.5	85.0	25.7	1.0
7	0.0	0.0	0.0	0.0	0.0	0.0	26.0	85.0	15.0	27.8	1.0
8	0.0	0.0	0.0	0.0	0.0	0.0	24.0	75.0	15.0	29.1	1.0
9	0.0	0.0	0.0	0.0	0.0	0.0	21.0	80.0	20.0	28.2	1.3

Notes: SC = Sediment concentration; VC = Vegetation cover; RFc = Rock fragment covers; ASM = Antecedent soil moisture

Table 3. Rainfall simulation results and environmental plot characteristics in the abandoned vineyard

ID	Runoff			Soil loss		SC, g l^{-1}	Slope	VC	RFc	ASM	Roughness, mm mm^{-1}
	l	l m^{2}	%	g	g m^{2}		%				
1	0.0	0.0	0.0	0.0	0.0	0.0	10.0	100.0	5.0	23.0	1.1
2	0.4	1.5	7.7	0.0	0.1	0.0	15.0	100.0	5.0	19.0	1.1
3	0.0	0.0	0.0	0.0	0.0	0.0	15.0	100.0	0.0	29.7	1.2
4	0.6	2.2	10.9	0.1	0.4	0.1	18.0	100.0	5.0	33.1	1.1
5	0.0	0.0	0.0	0.0	0.0	0.0	18.0	100.0	5.0	22.8	1.5
6	0.1	0.5	2.6	0.0	0.0	0.1	16.0	90.0	30.0	26.1	1.5
7	1.7	6.0	28.1	3.6	13.0	3.3	20.0	100.0	0.0	30.6	1.6
8	0.0	0.0	0.0	0.0	0.0	0.0	25.0	100.0	0.0	29.3	1.3
9	0.0	0.0	0.0	0.0	0.0	0.0	13.0	100.0	10.0	31.6	1.6
10	0.0	0.0	0.0	0.0	0.0	0.0	18.0	90.0	15.0	13.4	1.8
11	0.0	0.0	0.0	0.0	0.0	0.0	15.0	100.0	0.0	16.1	1.2
12	0.0	0.0	0.0	0.0	0.0	0.0	20.0	100.0	0.0	20.5	1.4
13	0.0	0.0	0.0	0.0	0.0	0.0	15.0	80.0	5.0	29.6	1.4
14	0.0	0.0	0.0	0.0	0.0	0.0	15.0	100.0	0.0	16.1	1.2

Notes: SC = Sediment concentration; VC = Vegetation cover; RFc = Rock fragment covers; ASM = Antecedent soil moisture

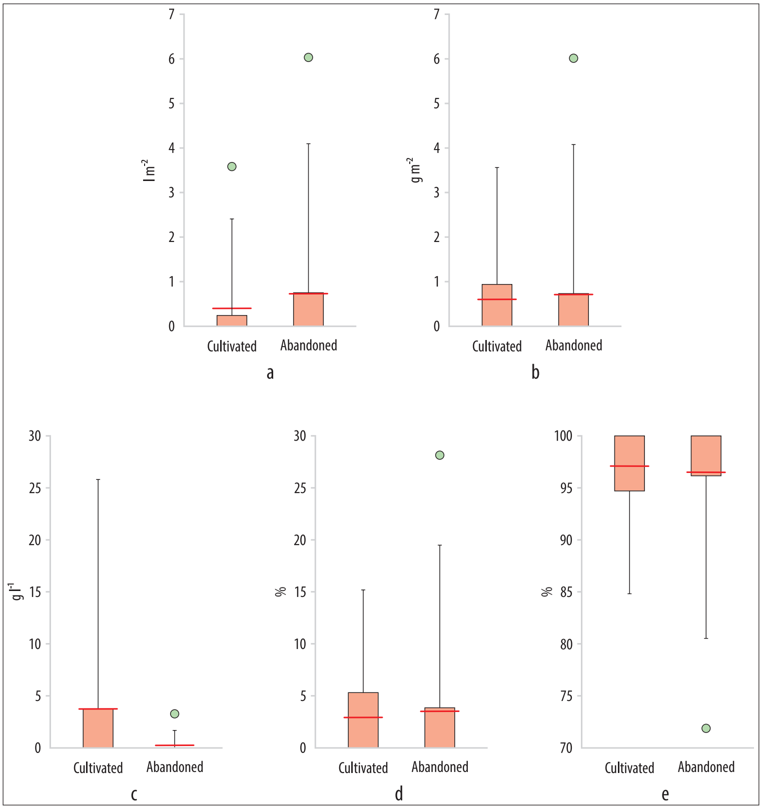

Fig. 4. Box plot of the soil erosion results in the cultivated and abandoned plots. – a = runoff; b = soil loss; c = sediment concentration; d = runoff coefficient; e = infiltration coefficient. Red dotted line represents the mean values.

In the vineyard, 56 per cent of the rainfall simulations do not obtain any runoff. On the other hand, in the abandoned field, a 71 per cent of the total experiments do not show water losses. In the cultivated plot, mean total runoff is 0.6 l m^2, reaching maximum values of 3.6 l m^2, meaning an average runoff coefficient of 3 per cent and maximums of 15 per cent. In the abandoned vine plantation, mean total runoff is 0.7 l m^2 and maximum values reach 6 l m^2. In terms of runoff coefficient, the abandoned plots show higher percentages, reaching mean values of 4 per cent and maximum amounts of 28 per cent.

These results confirm that after the abandonment and without a planned hillslope restoration, runoff can increase. These results are also coincident with other studied areas such as in the Mediterranean landscapes (Lasanta, T. *et al.* 2015). However, Mediterranean authors claim that this fact is due to bare soils, a decrease in porosity and an increase in soil Calcium carbonate crusts as a consequence of the high temperatures, low organic content and calcareous parent material (Romero Díaz, A. *et al.* 2007; Seeger, M. and Ries, J.B. 2008). In the studied vineyards, the main reason is that the vegetation cover, although very dense during winter and spring (>100%), is eliminated by the owners to maintain clean roads and drainages. As a consequence, the vegetation does not have enough time to act as a useful protection during the rainiest season of the year. Moreover, as we observed in the soil profiles´ description section, the sub-surface layers are strongly compacted in specific slope positions and the roots cannot develop a stable net. As a result, the infiltration capacity and water retention capacity could be reduced (Botta, G.F. *et al.* 2012).

In the cultivated plot, mean total soil loss show values of about 4 g m^2 and a maximum of 25.8 g m^2. Our findings register a mean sediment concentration of 3 g l^{-1} and a maximum of 7.8 g l^{-1}. In the abandoned vineyard, 1 g m^2 and 13 g m^2 are the mean and maximum soil loss values, respectively. Sediment concentration results in the abandoned vineyards are also lower than in the cultivated plots, reaching mean values of 0.3 g l^{-1} and maximums of 3.3 g l^{-1}. These results confirm that the vineyards are more devoted to registering initial soil erosion processes than the abandoned plots, as other authors in several countries also registered (Marques, M.J. *et al.* 2008; Chevigny, E. *et al.* 2014; Biddoccu, M. *et al.* 2017; Ben-Salem, N. *et al.* 2018). However, it is important to remark that future research should be focused on studies over a long-term period to observe if they overpass tolerable soil erosion rates or not (Verheijen, F.G.A. *et al.* 2009).

Finally, in *Table 4* and 5, Spearman rank´s coefficients are applied to observe which environmental factor acts as driving factor of soil erosion. In the cultivated plot, we observed that there is a strong correlation between the runoff generation and soil loss, and sediment concentration. These results also coincide with other crops, where bare soils and steep slopes generate a parallel increase in water and soil losses such as in olives or citrus orchards (Taguas, E.V. *et al.* 2015; Jianjun, W. *et al.* 2017). As recently mentioned, it exists a high correlation between bare soils and an increase of vegetation cover, which not only protect against soil and water losses, but also enhance nutrients retention (Olmstead, M.A. *et al.* 2001; Fourie, J.C. *et al.* 2016) and biodiversity development (Barrio, I.C. *et al.* 2012; Lopes, C. *et al.* 2015) as well. On the other hand, we observe that in the abandoned plot, only a high correlation is found with sediment concentration and antecedent soil moisture. This result also confirms that: i) when soils are saturated, soil and water losses are also activated, responding to a Hortonian dynamic (Imeson, A.C. and Lavee, H. 1998; Ziegler, A.D. *et al.* 2007); and, ii) vegetation cover reduces soil erosion activation, but a non-planned hillslope restoration modifies the hydrological dynamic, making it difficult to predict the spatial intra-plot variability.

Conclusions

This research pretends to demonstrate the significant changes in soil properties and initial soil erosion processes generated after vineyard´s abandonment. In *Figure 5,* we represented our findings which demonstrated that: i) in vineyards, there are several differences in soil properties and soil profiles among slope positions due to tillage and trampling effects, showing clear marks, features of compaction and soil depletion in the footslopes; ii) also, in the cultivated field, we registered higher mean and maximum values of soil loss and sediment concentration data

Table 4. Spearman rank´s coefficient in the cultivated vineyard

Indicators	Runoff	Soil loss	SC	RC	Slope	VC	RFc	ASM	Roughness
Runoff	–	0.994*	0.982*	1.000*	0.536*	-0.765*	0.755*	-0.152	0.126
Soil loss	–	–	0.994*	0.994*	0.531*	-0.755*	0.761*	-0.126	0.105
SC	–	–	–	0.982*	0.549*	-0.739*	0.755*	-0.121	0.110
RC	–	–	–	–	0.536*	-0.765*	0.755*	-0.152	0.126

Notes: SC = Sediment concentration; RC = Runoff coefficient; VC = Vegetation cover; RFc = Rock fragment covers; ASM = Antecedent soil moisture. *p<0.05.

Table 5. Spearman rank´s coefficient in the abandoned vineyard

Indicators	Runoff	Soil loss	SC	RC	Slope	VC	RFc	ASM	Roughness
Runoff	–	1.000*	0.854*	1.000*	0.270	0.048	0.134	0.369	-0.102
Soil loss	–	–	0.854*	1.000*	0.270	0.048	0.134	0.369	-0.102
SC	–	–	–	0.854*	0.381	-0.064	0.114	0.517*	0.077
RC	–	–	–	–	0.270	0.048	0.134	0.369	-0.102

Notes: SC = Sediment concentration; RC = Runoff coefficient; VC = Vegetation cover; RFc = Rock fragment covers; ASM = Antecedent soil moisture. *p<0.05.

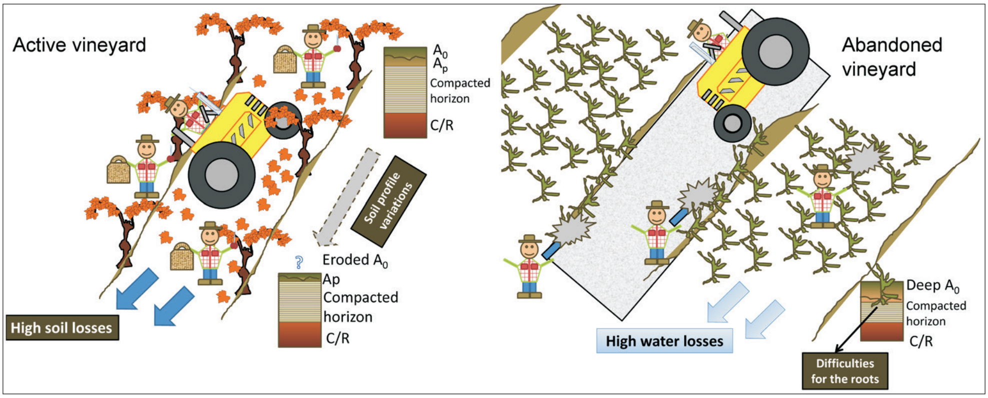

Fig. 5. Conclusions obtained from the cultivated and abandoned vineyards

than in the abandoned plot, being the vegetation cover and the steeper slopes the main driving factors; iii) on the contrary, in the abandoned plots a rapid homogenization of soil horizons and soil properties were found along the hillslope, where a deeper organic horizon was consistently developed on an underneath compacted and rocky horizon, which was developed during the cultivation phase; and, iv) due to high compaction and obstructed development of the roots, runoff and runoff coefficient were higher than in the cultivated plots.

Therefore, we claim that for the Central European vineyards under continental climate conditions, fortunately, at short-term periods, high facilities of a rapid recolonization and soil recuperation can be registered. However, any restoration plan that promotes a deep ploughing to remove the compacted sub-surface horizons and the prevention of annual pruning of vegetation after spring is not well suited for hillslope restoration and lessening soil and water losses.

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