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SOIL EROSION IN SLOPING VINEYARDS UNDER CONVENTIONAL AND ORGANIC LAND USE MANAGEMENTS (SAAR-MOSEL VALLEY, GERMANY)

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ABSTRACT. *German vineyards are one of the land uses most prone to soil erosion. Due to their placement on mainly steep slopes and non-conservative cultivation practices, runoff and soil loss are a serious problem for wine growers. In the Saar-Mosel valley (Rhineland-Palatinate, Germany), there is a tendency towards organic management of vineyards with protective grass cover in the inter-rows. Since there is a lack of information about organic-conventional tillage in German vineyards related to soil erosion processes, this study presents a comparison between these two soil management practices. For this purpose, 22 rainfall simulations were performed as well as a medium-term monitoring by using 4-paired Gerlach troughs in two experimental sites in the Saar-Mosel valley. The mean simulated runoff coefficient and suspended sediment load in conventional vineyards amounted up to 23.3% and 33.75 g m^{-2}, respectively. In the organic site, runoff and soil loss were only recorded in one out of the 11 simulations. Runoff and sediment was collected in the Gerlach troughs for 33 natural rainfall events. In the conventional vineyard, the total measured soil loss was 3314.63 g m^{-1} and 6503.77 g m^{-1} and total runoff volumes were 105.52 L m^{-1} and 172.58 L m^{-1}. In the organic site, total soil losses reached 143.16 g m^{-1} and 258.89 g m^{-1} and total runoff was 21.65 L m^{-1} and 12.69 L m^{-1}. When soil loss was measured without corresponding runoff or precipitation, soil erosion was activated by tillage or trampling. Finally, the conventional vineyard showed a higher variability in soil loss and runoff suggesting less predictable results.*

Erosión del suelo en viñas cultivadas en pendiente bajo sistemas de gestión convencional y orgánica (Valle de Saar-Mosela, Alemania)

RESUMEN. *Las viñas alemanas constituyen uno de los usos del suelo más susceptibles a la erosión. Debido a su emplazamiento sobre fuertes pendientes y a prácticas agrícolas poco sostenibles, la escorrentía y las pérdidas de suelo son un grave problema para los viticultores. En el valle del Sarre-Mosela (Renania-Palatinado, Alemania) existe actualmente una tendencia al manejo sostenible* *del suelo con medidas de protección como el uso de una cubierta vegetal entre calles. Dada la carencia de información sobre las diferencias erosivas entre laboreos convencionales y de conservación en las viñas alemanas, en este estudio comparamos ambos tipos de laboreo. Para ello, en dos parcelas experimentales localizadas en el Valle del Sarre-Mosela se realizaron 22 simulaciones de lluvia y se recogió el sedimento de 4 cajas Gerlach. Los resultados de las pruebas de simulación de lluvia en las viñas con laboreo convencional mostraron un coeficiente de escorrentía del 23.3% y pérdidas de suelo de 33.75 g m^{-2}. En la viña con laboreo de conservación, solo en una de las once simulaciones de lluvia se registró escorrentía y pérdida de suelo. Un total de 33 eventos naturales de lluvia fueron monitoreados con las cajas Gerlach. En las viñas con laboreo convencional las tasas de pérdida de suelo oscilaron entre 3314.63 g m^{-1} y 6503.77 g m^{-1} y el volumen de escorrentía superficial entre 172.58 L m^{-1} y 105.52 L m^{-1}. En cambio, en la parcela con laboreo de conservación los resultados de pérdida de suelo oscilaron entre 143.16 g m^{-1} y 258.89 g m^{-1}, y entre 105.52 L m^{-1} y 172.58 L m^{-1} el volumen de escorrentía. Se observó que el laboreo y las pisadas de los viticultores fueron la causa principal que generó sedimento en los eventos sin registro de escorrentía. Por último, se observó que el manejo convencional generó unos resultados más variables e impredecibles que el laboreo de conservación.*

Key words: soil erosion, organic vineyards, conventional vineyards, rainfall simulation, Gerlach trough.

Palabras clave: erosión, viñedo ecológico, viñedo convencional, simulación de lluvia, caja Gerlach.

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1. Introduction

Soils are one of the most important components of biological, hydrological and geochemical cycles (Brevik *et al*., 2015; Keesstra *et al*., 2012, 2016a) and thus are in a state of constant change and evolution (Simonson, 1959; Corbane *et al*., 2012; Novák *et al*., 2014). Transport of matter and energy through the soil (Bryan, 2000; Blum, 2005; Kovacs, 2012) is just one example of processes that show the dynamics of the pedosphere in part influenced by natural factors (Smith *et al*., 2015). Important biological and hydrological functions provided by the soil are at risk due to an anthropogenic overuse or mismanagement (Tarolli and Sofia, 2016; Tarolli, 2016), which can lead to erosion and degradation of soil, and the partial destruction of soil functions and resources (Costantini *et al*., 2015; Cerdà *et al*., 2016).

Vineyards are one of the land uses most prone to be heavily eroded by water (Prosdocimi *et al*., 2016a; Rodrigo Comino *et al*., 2016a; Cerdan *et al*., 2010) due to their oftentimes placement on steep slopes and non-conservative cultivation practices such as keeping the inter-rows bare during the whole year (Arnáez *et al*., 2007; Prosdocimi *et al.,* 2016b). Moreover, frequent use of heavy machinery (e.g. tractors) leads to a compaction of the top and subsurface layers in the ruts (Ferrero *et al*., 2005; Rodrigo Comino *et al.,* 2015; 2016c; 2016d). Rill erosion can be predominant over sheet erosion depending on the spatial scale and the environmental conditions, as shown by Quiquerez *et al*. (2008, 2014) and Chevigny *et al*. (2014). They concluded that over 30 % of fine material can be eroded with soil lowering up to 0.5 to 2 mm yr^{-1}, leading to a reduced soil fertility and sustainability. In the Penèdes region from northeast Spain and on Sicily in Italy, it was demonstrated that the cost of soil erosion in vineyards could amount to a great part of the final income from the sale of the grape production, as a result of the damaged infrastructures and cost associated to broad-based terraces, drainage channels or filling of ephemeral gullies, and washed off nutrients needing to be replaced (Martínez-Casasnovas and Ramos, 2006; Galati *et al*., 2015).

There are numerous types of management practices to be conducted in vineyards, concerning the soil cover in the inter-rows and rows. The soil can be kept bare through tillage or chemical weeding (no tillage necessary), while the most common and cheapest alternative is a permanent grass cover or the application of straw mulches (García Díaz *et al*., 2016; Morvan *et al*., 2014; Prosdocimi *et al*., 2016b). In semiarid areas, farmers keep the soils bare mostly to avoid the competition for water and nutrients by weeds (Ramos and Martínez-Casasnovas, 2006; Raclot *et al*., 2009) or to improve the accessibility of the vineyard.

Organic farming in vineyards aims towards a higher sustainability and biodiversity of the soil, including soil fauna (Reinecke *et al*., 2008; Bruggisser *et al*., 2010) or microbial biomass (Probst *et al*., 2008). Grass cover was shown to reduce soil and nutrient losses compared to tilled soils (Biddoccu *et al*., 2016; Morvan *et al*., 2014; Rodrigo Comino *et al*., 2016a, 2016b). Mulching is another possibility to reduce runoff and erosion, where cut grass, straw or other organic materials (Hueso-González *et al*., 2014, 2016, 2017) form a thin protective blanket over the bare soil (Stigter, 1984). A similar method is the use of geotextiles to shield the soil from runoff and provide favourable soil moisture conditions (Kertész *et al*., 2007; Giménez-Morera *et al*., 2010), but is more expensive. Soil conservation measures proved to reduce soil and nutrient losses with no tillage (Keesstra *et al*., 2016b; Cerdà *et al*., 2016).

German vineyards are located close to the European northern boundary for wine-growing above which pedoclimatic conditions do not allow grape ripening due to the low temperatures (Ashenfelter and Storchmann, 2010a, 2010b; Koch *et al*., 2013). However, the introduction of new plantations with conventional management and the use of heavy machinery are enhancing land degradation processes such as soil erosion, which can be observed at hillslope and pedon scales. Some consequences related to soil erosion processes in some studied conventional managements (Hacisalihoglu, 2007; Richter, 1980, Rodrigo Comino *et al*., 2015, 2016c) are the high disturbance of the soil profile during the initial plantation, rill and ephemeral gully formations due to wheel traffic impacts for tilling and ploughing, and high runoff and soil loss rates. However, there is currently a lack of information about quantifications of soil erosion and hydrological processes in short- and medium-term periods and its mechanisms at intra-plot scale compared to other managements. Therefore, the aim of this study is to compare the rates of runoff and soil losses in a context of simulated events (rainfall simulations) and natural events (in open plots) with different land managements such as conventional (bare soils) and organic (grass cover) farming.

2. Materials and methods

2.1. Study area

The study site is located close to the village of Kanzem (Fig. 1) in the Saar-Mosel Valley (49.6667 N; 6.5756 E, Rhineland-Palatinate, Germany). The two chosen vineyards were both planted with the Riesling grapevines variety and situated next to each other, but one being conventionally and the other organically managed.

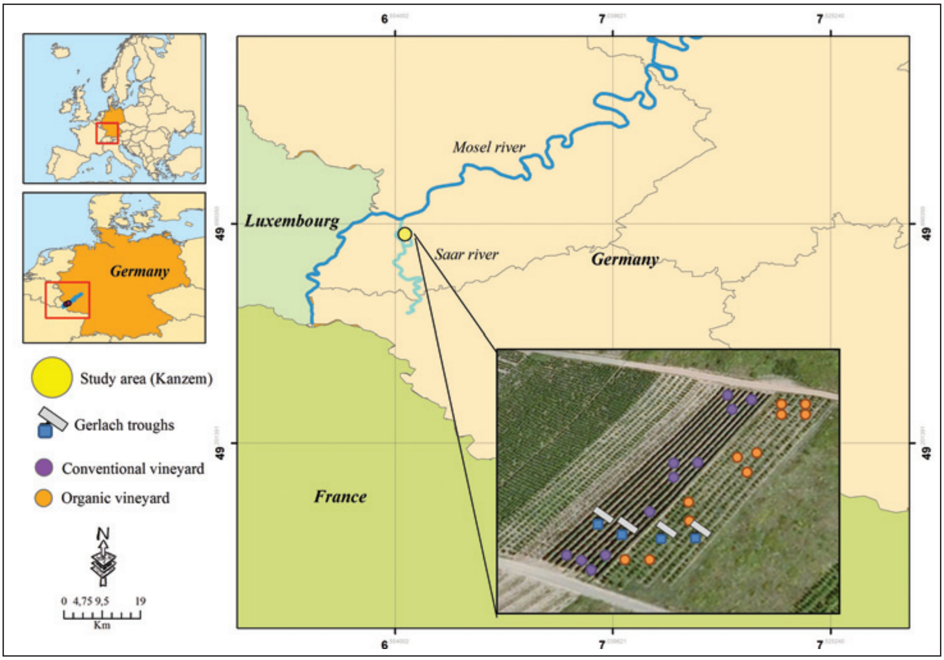

Figure 1. Study area.

The average air temperature is 14.1°C, the total annual rainfall is 749 mm (http://www.wetter.rlp.de). The vineyards are located at an altitude between 150-250 m, with the slope ranging from 17° to 35°. The soils of both vineyards can be described as *leptic-humic Regosols* (IUSS Working Group WRB, 2014). They show a higher sand content in the organic (60.9 %) than in the conventional vineyard (49 %). The latter is also characterized by high silt contents (40.4 %). The organic matter content is higher in the conventional vineyard (10.6 %) than in the soils with organic management (5.4 %). The organic vineyard is cultivated with old vines on single poles planted in 1967, the conventionally managed vines are about 30 years old.

Organic viticulture is a type of management that aims at preserving soil functions, biodiversity and vegetation cover on the vineyard without using synthetic fertilizers or herbicides/pesticides and is regulated by certifiers accredited to the European Convention (regulation–EU–No 203/2012). The soil tillage in the studied organic vineyard is mainly conducted from the end of March until May as well as in summer before the harvest. Mechanized measures include harrowing, mulching and grubbing, while hoeing under the rows and grass cutting are performed without heavy machinery but by hand or with a brush-cutter. Machines used are a narrow tractor with an attached mower or alternatively rotary harrows, a grubber with either sub-soilers or wing shares as well as a hand-operated crawler with a shredder. Those practices are taken to loosen the soil, mineralize nutrients at growth or blossoming of the vine, minimizing drought stress, breaking capillaries, removing rival plants and preparing the seedbed for revegetation between the rows. The soil tillage varies from year to year depending on the weather (between 5-8 times from March to August, mechanized measures). The tillage practices in the conventional vineyard are mainly done by mechanical tilling and ploughing before and after grape harvesting in the first 20 cm of depth (spring and early autumn). The presence of mulch and grass covers is common, as well as the use of slates covering the soil to protect the surface against the rain splash effect and cold temperatures. Finally, herbicides and fungicides are applied during spring and summer, spraying on several occasions.

2.2. Methods

2.2.1. Small portable rainfall simulation and plots

We used a modified nozzle-type rainfall simulator (Cerdà, 1999). A detailed description can be found in Iserloh *et al.* (2012). A nozzle Lechler 460 608 was used, spraying from 2 m height. The tested plots were circular with a diameter about 60 cm and a total area of approximately 0.28 m^2. A reproducible artificial rainfall is set by managing a flow control. This small portable rainfall simulator was always calibrated for a rainfall intensity of 40 mm h^{-1} to allow comparing both areas. This can be considered occasional rainfall intensity for events with low occurrence in the Saar-Mosel valley (Reiter *et al.*, 2016; Rodrigo Comino, 2015). We assumed the rainfall intensity (kinetic energy and drop size distribution) using the calibration of Iserloh *et al*. (2012, 2013a) to be able to compare results from regions with differing natural rainfall intensities. We measured the rainfall intensity at the beginning and at the end of the test; only when the intensity was constant (a maximum difference of 5 % to 10 %), the experiment was considered successful. Experiment durations were 30 minutes. All of the rainfall simulations were conducted between 2014 and 2015 on representative plots.

Plot characteristics such as vegetation and stone cover, roughness (using the chain method by Saleh, 1993), slope and previous soil moisture were measured. During the experiment, total runoff and mobilized materials were sampled in PE bottles. The

30-minutes-experiments were divided into six intervals (five minutes each). At the beginning of every new interval, the bottles were changed. In the laboratory, the bottles were weighed and the total runoff (L) was obtained gravimetrically, subtracting also the sediment amount. The collected water in every bottle was filtered separately with circular fine-meshed filter papers. Every filter was dried at 105 °C and weighed for obtaining total soil material for each interval.

A total of 22 rainfall simulations were conducted between October (2014) and April (2015), 11 in the conventional vineyard and 11 in the organic one.

Several differences of plot characteristics of both study sites can be noted (Table 1). Although the slope is fairly similar with 17.6 ± 5.1° in the conventional vineyard and 16.9 ± 4.9° in the organic one, vegetation cover in the organic vineyard reaches up to 78.6 ± 14.8 %, but only 36.8 ± 32.2 % in the conventional one. The latter shows a stone cover of 34.3 ± 25.2 %, while the former displays lower values of 22.3 ± 15.1 %. Plot roughness values were basically the same for both study sites (≈1). At the beginning of the simulation, antecedent soil moisture values were higher in the conventional (13.9 ± 1.6 %) than in the organic vineyard (11.8 ± 5.8 %).

Table 1. Environmental characteristics of the studied areas.

	Clay	Silt	Sand	Slope (°)	Vegetation cover (%)	Stone cover (%)	Soil moisture (%)
Conventional	10.6	40.4	49	17.6±5.12	36.8±32.2	34.3±25.2	13.9±1.6
Organic	8.1	31	60.9	16.9±4.9	78.6±14.8	22.3±15.1	11.8±5.8

2.2.2. Gerlach troughs

The Gerlach trough design was developed by Rüttimann and Prasuhn (1993) following the approach of Gerlach (1967), and tested previously for soil erosion measurements on maize crops (Rüttimann *et al.*, 1995) and German conventional vineyards (Rodrigo Comino *et al*., 2015; 2016b). Four sediment collectors with a width of 150 cm (Fig. 2) were situated in the inter-rows and part of the rows (about 1 meter width) on the backslopes in both tested areas. Amounts of sediment (g), overland flow (L) and sediment concentration (g L^{-1}) were calculated proportionally in g m^{-1}, L m^{-1} and g L^{-1}, respectively (Gerlach, 1967). The open soil erosion plots give information about the soil and water losses but the contributing area is uncertain, which is why the soil erosion rates or overland flow are shown in g m^{-1} and L m^{-1}, respectively. Additionally, all of them are connected to collecting tanks (100-200 L) to be prepared for extreme rainfall-runoff events that exceed the storage capacity of each Gerlach trough (upwards from 30 L). Close to the sediment collectors in both vineyards, an agro-climate station (http://www.wetter.rlp.de) delivered the rainfall amount and intensity after each event. The upslope length in the vineyards was approximately 60-80 m. The main limit of this tool is the impossibility to collect the water inflow from sub-surface flow. The maintenance of the equipment, emptying sediments and overland flow, was performed every one to four weeks, depending on the rainfall events. All collected samples were transported to the laboratory for drying, weighing and quantifying sediments and overland flow. The soil erosion monitoring was carried out between 22.04.2015 and 17.08.2016, containing a total of 33 natural rainfall events. When the rainfall did not activate the overland flow but soil loss occurred, anthropogenic factors (trampling of workers, machinery, removal and re-placement of troughs) were the main cause to initiate the soil erosion events.

Figure 2. Gerlach troughs in the studied plots. A: conventional vineyard; B: organic farming.

2.2.3. Statistical analysis

Rainfall simulation results were represented in form of box plots, showing the medians (continued line), the averages (discontinued line) and outliers.

Soil erosion results from the open plots were organized following events with little to moderate precipitation (<20 mm) and high erosion results (>5 g m^{-1}), and events with larger amounts of rainfall (>20 mm) that led to a lower soil losses (<5 g m^{-1}). Moreover, to compare the variability of the results the relative difference in the replicated erosion plots proposed by Nearing *et al.* (1999) was used.

$$Eq.\ 1\ R_{\text{diff}}\ \frac{M2-M1}{M2+M1} \qquad (1)$$

M1 and M2 are the paired values of soil loss and overland flow from two replicate plots. The values can vary between -1 and +1. When M2 = M1, the relative differences among them are avoided. The second comparison of the soil loss and overland flow results from the paired-Gerlach troughs was performed using a Mann-Whitney Rank Sum Test with the SigmaPlot 13 (Systat Software, Inc).

3. Results

3.1. Rainfall simulation results

The results of the 22 rainfall simulations are presented by showing the total averages, maximum and minimum values (Fig. 3) and per interval (Fig. 4) in box plots.

The conventional vineyard showed a total average suspended sediment load (SSL) of 33.75 g m^{-2} with maximum values about 96.8 g m^{-2}, while the mean runoff (R) was 5.25 L m^{-2}. The maximum runoff observed was 17.03 L m^{-2}. The average suspended sediment concentration (SSC) was therefore 4.26 g L^{-1} (maximum values reached up to 10.93 g L^{-1}), with a mean runoff coefficient (RC) about 23.33 % and an average infiltration coefficient (IC) of 76.67 %. The maximum runoff coefficient was 60.5 %, while the minimum infiltration coefficient was 39.5 %. During the experiment (Fig. 4), the average interval values showed the runoff starting during the first interval on the conventional vineyard and rising to the sixth interval reaching its maximum. Erosion was also present from the first interval, decreasing in the second to rise again until the fifth interval and still showing high values in the sixth. The highest runoff coefficient and the lowest infiltration coefficient were also found in the sixth interval, while the highest sediment concentration was present in the fourth interval.

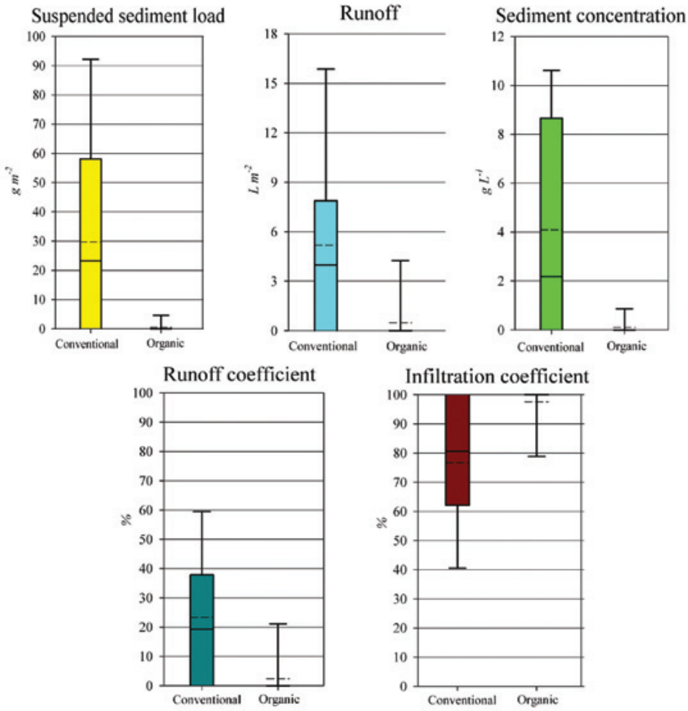

Figure 3. Total average of suspended sediment load, runoff, sediment concentration, runoff and infiltration coefficients (5th/95th percentiles; short dash: mean line; solid line: median).

In the organic vineyard only one of 11 simulations produced runoff and erosion (Fig. 3). The 10 remaining simulations showed infiltration coefficients of 100 % and therefore no suspended sediment load. The unique simulation that showed soil erosion obtained a total runoff of 5.32 L m^{-2} and suspended sediment load about 5.75 g m^{-2}. The total suspended sediment concentration was 1.08 g L^{-1}, with a total runoff coefficient of 26.40 % and a corresponding infiltration coefficient of 73.6 %. During the simulation (Fig. 4), the maximum suspended sediment load and runoff were 2.89 g m^{-2} and 2.84 L m^{-2}, respectively. Runoff began in the fourth interval, rising up to the sixth interval where it reached its maximum. Sediment yield reached its maximum in the fifth interval and declined slightly in the sixth. Thus, the value for the runoff coefficient was the highest in the sixth interval, while the highest sediment concentration was found in the fifth interval. The average for all 11 simulations was therefore: R = 0.08 L m^{-2}, SSL = 0.09 g m^{-2}, SSC = 0.05 g L^{-1}, RC = 2.40 % and IC = 97.60 %.

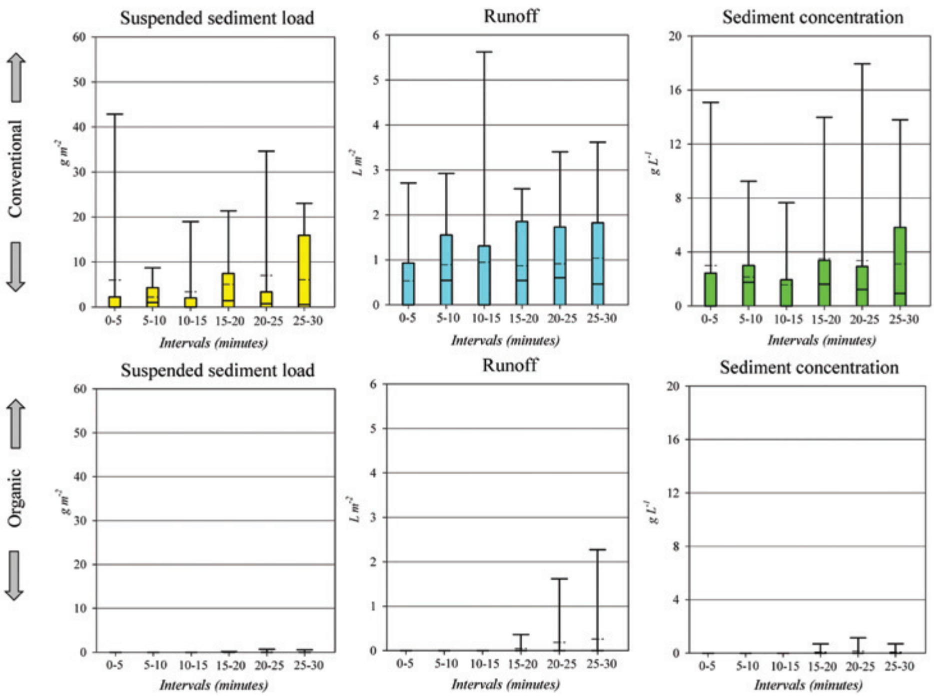

Figure 4. Total means per intervals of suspended sediment load, runoff and sediment concentration (5th/95th percentiles; short dash: mean line; solid line: median).

3.2. Monitoring of overland flow, soil loss and sediment concentration

The recorded rainfall events as well as mean and maximum rainfall intensities are shown in Table 2. The highest rainfall was measured to be 106 mm by 14.06.2016, while the minimum added up to 4.4 mm by 14.07.2015. During the months April-September 5 out of 7 rainfall events with a total rainfall of more than 40 mm were quantified. The events with the highest maximum rainfall intensities also occurred in summertime, while events with lower maximum rainfall intensities occurred mostly in winter. The highest maximum rainfall intensity as well as the maximum mean rainfall intensity was measured on 22.07.2016 with 30.8 mm h^{-1} and 1.93 mm h^{-1}, respectively.

Table 2. Climate conditions during the monitoring period.

ID	Date	Total	$\acute{x}$	Max.	ID	Date	Total	$\acute{x}$	Max.
1	22.04.2015	14.6	0.2	1.2	18	14.12.2015	9.6	0.26	1.8
2	28.04.2015	24	0.46	4.8	19	26.01.2016	49.2	0.27	3
3	12.05.2015	12.6	0.3	1.2	20	03.02.2016	20.2	0.4	2.6
4	19.05.2015	7.4	0.6	0.6	21	11.02.2016	25.8	0.5	3.6
5	02.06.2015	14.2	0.55	3.6	22	25.02.2016	33.4	0.35	3.2
6	16.06.2015	16	4	11.6	23	05.04.2016	70.2	0.34	3.6
7	30.06.2015	32.4	1.4	4	24	21.04.2016	18	0.43	2.8
8	14.07.2015	4.4	0.65	2.2	25	03.05.2016	37.5	0.33	1.7
9	21.07.2015	15.2	1.06	9.8	26	18.05.2016	11.1	0.31	1.7
10	29.07.2015	16.2	0.63	5.8	27	31.05.2016	71.5	0.63	10.3
11	05.08.2015	8	0.5	3	28	14.06.2016	106	1.6	15.8
12	26.08.2015	22	0.6	2.8	29	23.06.2016	26.2	1.01	7.7
13	03.09.2015	46	1.6	7.8	30	28.06.2016	18.2	1.16	3.6
14	20.10.2015	94.4	0.38	4.2	31	22.07.2016	75	1.93	30.8
15	10.11.2015	6.2	0.2	0.6	32	11.08.2016	19	0.25	2.6
16	20.11.2015	38.8	0.45	4.4	33	17.08.2016	0.1	0.1	0.1
17	01.12.2015	16	0.3	2.4					

* Total: total rainfall (mm); $\acute{x}$: mean rainfall intensity (mm h^{-1});
Max.: maximum rainfall intensity (mm h^{-1}).

Out of 33 recorded rainfall events (Table 3), 21 lead to runoff in Gerlach trough 1 as well as 14 in trough 2 (both conventional vineyard), while 11 produced runoff collected in troughs 3 and 4 (both organic vineyard). The total runoff observed was 172.58 L m^{-1} (Gerlach trough 1) and 105.52 L m^{-1} (Gerlach trough 2) in the conventional vineyard. The values collected in the organic vineyard (Gerlach troughs 3 and 4) were 21.65 L m^{-1} and 12.69 L m^{-1}. The maximum value for overland flow was 52.44 L m^{-1} on the conventional vineyard, whereas the maximum on the organic was 10.31 L m^{-1} during the same event. In Table 4, the relative difference proposed by Nearing *et al.* (1999) showed that there was a high variability in the tow-paired sampling sediment collectors in the conventional vineyard (R_{diff} = -0.32), which were confirmed with the Mann-Whitney

Rank Sum Test with a statistically significant difference in the median values of the two troughs ($P = 0.05$), meaning the difference was great enough to exclude the possibility that the difference was due to random sampling variability. On the other hand, there was no statistically significant difference for the Gerlach troughs on the organic vineyards ($P = 0.976$, $R_{diff} = 0.0051$).

Table 3. Total soil loss, overland flow and sediment concentration results in conventional and organic vineyards.

Soil management	Conventional		Organic	
Gerlach trough	1	2	1	2
Overland flow (L m^{-1})	172.58	105.52	21.65	12.69
Soil loss (g m^{-1})	6503.77	3314.63	258.89	143.16
Sediment concentration (g L^{-1})	37.69	31.41	11.96	11.28
Total rainfall (mm)	979.4			

Table 4. Relative differences in two-paired erosion plots.

Soil management	Conventional		Organic	
Soil erosion parameters	Overland flow	Soil loss	Overland flow	Soil loss
R_{diff} (Nearing *et al.*, 1999)	-0.32	-0.37	0.0051	-0.055
Mann-Whitney Rank Sum Test	P = 0.05	P = 0.05	P = 0.976	P = 0.783

The total soil loss on the conventional vineyard added up to 6503.77 g m^{-1} (Gerlach trough 1) and 3314.63 g m^{-1} (Gerlach trough 2). The total soil losses in the organic vineyards reached up to 258.89 g m^{-1} for Gerlach trough 3 and up to 143.16 g m^{-1} for the other paired-one (4). Maxima amounted to 2500 g m^{-1} in the sediment collector 2 (75.4 % of the total soil loss in one event) in the conventional vineyard and up to 125.09 g m^{-1} in the Gerlach trough number 4 (87.4 % of the total soil loss in one event) in the organic vineyard. As with the overland flow, the soil loss values in the conventional vineyard also showed statistically significant differences between the soil erosion rates ($P = 0.05$, $R_{diff} = -0.37$). The R_{diff}-value (Nearing *et al.*, 1999) in the organic vineyard amounted to -0.055, while the Mann-Whitney Rank Sum Test obtained a P-value of 0.783, both showing no difference in data and the median (almost any variability), respectively.

It becomes apparent in Figures 5 and 6 that the soil losses had no clear relationship with rainfall amounts and intensities. When focusing on events from little to moderate total precipitation (<20 mm) and high erosion rates (>5 g m^{-1}) the events 6, 9, 11, 24, 30 and 32 are singled out (Table 5). All of these events coincided with soil tillage practices, like ploughing, pruning and harvesting, although events 6 and 9 showed a high maximum rainfall intensity (Table 2). Events 24 and 32 induced high erosion in 3 out of 4 Gerlach troughs. These events occurred on 21.04.2016 and 11.08.2016, respectively. Gerlach trough 1 collected eroded sediment during the events 11 and 30, which did not show high maximum rainfall intensities although they occurred during the summer months (5.08.2015 and 28.06.2016, respectively) when soil is frequently tilled. Although not shown in Table 5, event 2 activated erosion but no runoff, which could be an indicator for tillage erosion. Table 5 also shows events with precipitation >20 mm that led to a soil loss of <5 mm. The number of events to fit this restriction amounts to 6 - 9 in the conventional and 12 - 14 in the organic vineyard.

Table 5. Characterization of natural rainfall events in the studied conventional and organic vineyards.

		Conventional		**Organic**	
Type of events	Rainfall/erosion	Gerlach trough 1	Gerlach trough 2	Gerlach trough 3	Gerlach trough 4
<20 mm >5 g m^{-1}	Number of event	6, 9, 11, 24, 30, 32	9, 24, 30, 32	24, 32	
	Total (mm / g m^{-1})	94.4 / 929.3	70.4 / 2667.1	37.0 / 98.6	- / -
>20 mm <5 g m^{-1}	Number of event	12, 16, 20, 22, 23, 25	7, 12, 14, 16, 19, 20, 22, 23, 25	2, 7, 13, 14, 16, 20, 22, 23, 25, 27, 29, 31	7, 12, 13, 14, 16, 20, 21, 22, 23, 25, 27, 28, 29, 31
	Total (mm / g m^{-1})	222.1 / 5.7	398.1 / 6.3	569.6 / 8.4	699.4 / 9.3

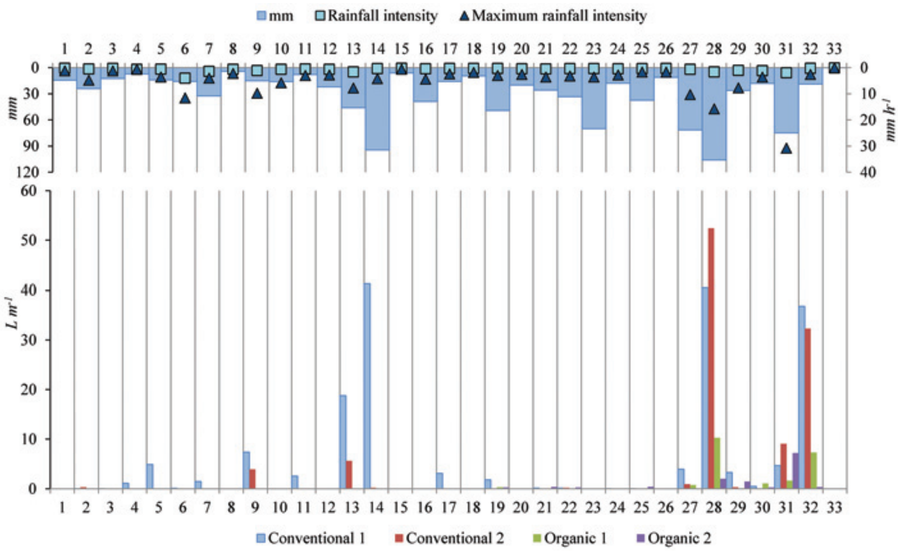

Figure 5. Total rainfall events and overland flow in organic and conventional vineyards.

4. Discussion

A comparison of runoff and soil loss in conventional and organic vineyards was carried out using a portable rainfall simulator as well as Gerlach field troughs. Although the two methods (simulations vs. open plots) cannot be compared directly, both showed great differences between the management types.

Despite that rainfall intensity was higher during the rainfall simulations than during natural events, soil losses and runoff coefficients were higher during the natural events due to the relatively low kinetic energy of the simulated rainfall and the inexact reproduction of the natural rainfall structure by rainfall simulations (Cerdà, 1997; Iserloh *et al*., 2012; Iserloh *et al*., 2013b; Lassu *et al*., 2015). Comparison of both measurement methods is difficult since there is no data about the contributing area during natural events, although it is probably larger than the plots of the rainfall simulations (Chaplot and Le Bissonnais, 2000; Kinnell, 2016) and highly variable between different events and even within an event. In addition, on the open plots, human impact during vineyard management had a high influence on sediment transport (trampling effect, use of machinery, etc.). The complexity of the processes generating transport of sediments is also higher on these plots, since concentrated flow can have a big influence on the measured soil losses in the Gerlach troughs.

Little to no runoff and soil loss were measured in the organic vineyard with grass-cover between the lines of wine. Soil sealing has been identified to be one of the main responsible for runoff generation on agricultural land (Peter and Ries, 2013; Hänsel *et al.*, 2016), which did not happen in the studied organic vineyards and thus explains the absence of runoff in 10 of 11 experiments. This could also show effects on grape production, quality of wine and carbon capture and storage (García-Díaz *et al.*, 2017; Marín *et al.*, 2016; Novara *et al.*, 2015). In contrast, the conventionally managed vineyard produced considerably higher values for runoff and soil loss.

Suspended sediment load has been measured in other viticulture areas with different soil management strategies. In Spain, Prosdocimi *et al*. (2016b) measured on bare and straw-mulch covered soils SSC of 9.8 g L^{-1} and 3.0 g L^{-1}, respectively. These values are considerably higher than those measured in the Saar-Mosel Valley, with 2.07 g L^{-1} in the conventional and 0.00 g L^{-1} in the organic vineyard. In comparison to other orchards in the western Mediterranean, these values are also remarkably low: mean SSC values from 1.0 g L^{-1} (straw-covered soil) to 10.9 g L^{-1} (bare soil) were obtained by rainfall simulations in persimmon plantations (Cerdà *et al*., 2016) in Spain, and from 1.5 g L^{-1} (vegetation cover) and 4.55 g L^{-1} (herbicide use) to 13.65 g L^{-1} (tilled soils) in apricot orchards (Keesstra *et al*., 2016b). Hence, the average SSC in the conventional vineyard (2.77 g L^{-1}) of the present study was lower than the SSC measured under uncovered crops but higher than the values obtained under protective covers.

The results can also be compared to those found in vineyards in other areas: in Spain, median values of SSC reached approximately 6 g L^{-1} in Málaga and Valencia (Rodrigo Comino *et al*., 2016a). In the Ruwer Valley (Germany), close to the vineyards presented here, on steep conventionally managed vineyards of different ages, average

SSC were for 4 years old vines 7 g L^{-1} and for 35-40 years old vines 6.2 g L^{-1}. In these steep vineyards under conventional management in Spain and Germany, sediment concentrations are similar because the areas are characterized by shallow and unprotected bare soils. The vineyard with organic management showed sediment concentrations close to zero, much lower than all the conventionally managed vineyards of different ages in the region, located on the same geological substrate (Rodrigo Comino *et al*., 2015, 2016a), suggesting that the determining factor for soil erosion control is the management type.

In a study carried out in Spanish vineyards, SSC generated by natural rainfall events and collected in Gerlach-troughs ranged from 0.2 to 27 g L^{-1}, depending on the disturbance of the soil (Ramos and Martínez-Casasnovas, 2007). On the steep slopes of the Saar vineyards, the highest sediment concentrations reached up to 6792 g L^{-1}. These samples were characterised by large amounts of coarse material and soil, and were collected without or with very low rainfall and runoff amounts, suggesting soil and sediment translocation by trampling and tillage activities. Excluding these extreme values, SSC ranged from 0.1 g L^{-1} to 127 g L^{-1}, showing higher values than the ones obtained in Spain.

Albeit similar conditions regarding slope gradient and soil type, runoff and soil loss measured with rainfall simulations were also higher in the conventional vineyard than in the organic one. On the other hand, the conventionally managed vineyard soils showed a higher content of soil organic matter. This suggests that differences in runoff and erosion intensities cannot be explained by single soil parameters, but by the development or degradations status of the soil (see also Seeger, 2007). Although the surface cover varies between the two management types, it might not be the only reason for the difference in the initial soil erosion processes. The age of the vineyard is also a key factor controlling soil erosion intensity. Rodrigo Comino *et al*. (2015; 2016e) observed via botanic benchmarks on recently planted vineyards (approx. 4 yr) a decrease of soil erosion rates from 62.5 Mg ha^{-1} yr^{-1} to 33.5 Mg ha^{-1} yr^{-1} in two years, whilst the erosion rates on old vineyards (>30 yr) were one order of magnitude lower (decreasing in the same period from 3.4 Mg ha^{-1} yr^{-1} to 3.3 Mg ha^{-1} yr^{-1}). This shows that the plantation of vineyards leads to the highest soil erosion rates, which decrease substantially with time.

The plantation scheme on the steep sloping vineyards in the Mosel area has been designed for the use of machinery for soil and plant management. Its impact on soils, e.g. compaction, has been observed by different authors (Rodrigo Comino *et al*., 2016a; 2016c; Cerdà *et al*., 2016). Lieskovský and Kenderessy (2014) compared different soil managements such as hoeing by hand and using machinery, and confirmed that the first one was protective for the soils, whereas the second considerably enhanced soil erosion. Despite the use of machinery in the organic management of our test sites, hoeing by hand is still an important management practice and could therefore also explain also the lower erosion rates.

In this study, some soil erosion events were produced by trampling. Soil translocation by trampling has also been observed during harvest and under other crops in Spain and Germany (Rodrigo Comino *et al.*, 2015; 2016b). Effects of human trampling on soils and soil erosion were also reported under dense vegetation (Quinn *et al.,* 1980), as well as effects on soil compaction of forest soils under heavy use (Godefroid and Koedam, 2004). As a large part of the management of the organic vineyard is done without machinery and with high frequency, this may be an important contribution to soil erosion. The event 2 (Fig. 6), which activated erosion but no runoff in Gerlach trough 4, occurred during the harvest period, where the vine growers pass several times for selecting the best mature grapes.

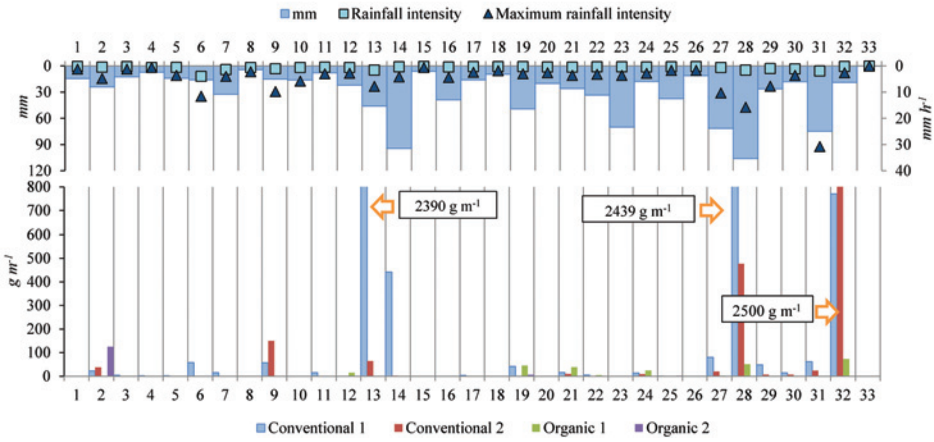

Figure 6. Total rainfall events and soil loss in organic and conventional vineyards.

There was a high variability between the values of the two Gerlach troughs installed in the conventional vineyard, as shown by the R_{diff}-values (Nearing *et al.*, 1999) and the Mann-Whitney Rank Sum Test (Table 4). There was no statistical indication that the same variability existed in the organic vineyards. Since the Gerlach troughs in this study encompassed the total width between the individual rows, they also collected runoff and erosion from compacted wheel tracks in both the organic and conventional vineyard. The soils of the organic vineyard were possibly less compacted than those on the conventional one and also showed a dense vegetation cover, thus stopping runoff nearly completely. Nearing *et al.* (1999) also noted that when erosion values are low, more plots are needed to obtain a certain level of similarity. The results shown in this study do not agree with Nearing's conclusion, since there is no statistical variability in the results of the organic vineyard, where values are low, but rather in the high soil loss-yielding conventional vineyard. There are however uncertainties about how long the monitoring period and how big the plot should be to obtain reliable data. The statistical methods used here lead to the conclusion that soil loss in conventionally managed vineyards shows a higher spatial variability than in organic vineyards. But further monitoring is needed, if possible with a higher temporal resolution, to confirm this variability. Soil loss in organically managed vineyards clearly related to the density of the vegetation cover amongst other factors (Morvan *et al*., 2014).

Since erosion in vineyards is a wide-spread problem (Rodrigo Comino *et al.*, 2016d; Prosdocimi *et al.*, 2016a; Biddoccu *et al.*, 2016), different management strategies are applied to reduce it. Grass cover or cover crops are often used to reduce runoff and erosion (Biddoccu *et al*., 2016, Ruiz-Colmenero *et al*., 2011, 2013, Novara *et al.*, 2011) but in some other cases they can enhance the variability of runoff and soil loss since the grass cover is not dense enough to halt runoff in the wheel tracks (Morvan *et al*., 2014; Sastre *et al*., 2016). Blavet *et al*. (2009) found that especially two factors were controlling runoff generation and erosion: soil cover (by vegetation, mulch or pruning residues) and the topsoil aggregate stability. Both hinder the formation of impermeable crusts.

5. Conclusion

For this study 22 rainfall simulations were carried out in conventionally and organically managed vineyards. Monitoring results were acquired using 4 Gerlach troughs. The conventional vineyard showed higher soil loss during the rainfall simulations than the organic one, which was unresponsive in terms of runoff and soil loss during 10 out of 11 rainfall simulations. Erosion could be activated by soil tillage and without precipitation or runoff. This was measured by the Gerlach troughs placed in the field.

Finally, the conventional vineyard showed a high variability concerning runoff and soil loss between the two Gerlach troughs placed in two adjoining rows in the field. The organic vineyard showed no such variability, though the measured soil erosion was very much lower than the one measured in the conventionally managed vineyard.

This information could be a good reference point for future land management planning and can help the wine growers with their decisions.

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