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# Soil Erosion Processes in European Vineyards: A Qualitative Comparison of Rainfall Simulation Measurements in Germany, Spain and France

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**Abstract:** Small portable rainfall simulators are considered a useful tool to analyze soil erosion processes in cultivated lands. European research groups in Spain (Valencia, Málaga, Lleida, Madrid and La Rioja), France (Reims) and Germany (Trier) have used different rainfall simulators (varying in drop size distribution and fall velocities, kinetic energy, plot forms and sizes, and field of application) to study soil loss, surface flow, runoff and infiltration coefficients in different experimental plots (Valencia, Montes de Málaga, Penedès, Campo Real and La Rioja in Spain, Champagne in France and Mosel-Ruwer valley in Germany). The measurements and experiments developed by these research teams give an overview of the variety of methodologies used in rainfall simulations to study the problem of soil erosion and describe the erosion features in different climatic environments, management practices and soil types. The aims of this study are: (i) to investigate where, how and why researchers from different wine-growing regions applied rainfall simulations with successful results as a tool to measure soil erosion processes; (ii) to make a qualitative comparison about the general soil erosion processes in European terroirs; (iii) to demonstrate the importance of the development of standard method for measurement of soil erosion processes in vineyards, using rainfall simulators; and (iv) and to analyze the key factors that should be taken into account to carry out rainfall simulations. The rainfall simulations in all cases allowed infiltration capacity, susceptibility of the soil to detachment and generation of sediment loads to runoff to be determined. Despite using small plots, the experiments were useful to analyze the influence of soil cover to reduce soil erosion, to make comparisons between different locations, and to evaluate the influence of different soil characteristics. The comparative analysis of the studies performed in different study areas points out the need to define an operational methodology to carry out rainfall simulations, which allows us to obtain representative and comparable results and to avoid errors in the interpretation in order to achieve comparable information about runoff and soil loss.

**Keywords:** rainfall simulation; soil erosion; soil hydrology; qualitative comparison; vineyards

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## 1. Introduction

The concept of terroir defines a vineyard with particular regional vitivinicultural practices (land management, soil tillage, crop management, *etc.*) and identifiable bio-physical environmental conditions (soil, climate, landscape and topography) with direct influences on grape composition [1–4].

Several authors evidenced the importance of vineyard degradation during the last few decades, induced by applying chemical weeding, seasonal intensive tillage, green pruning and the use of heavy machinery [5–9]. All these activities notably affect one of the most important components of the terroir: the soil. Pedological process research in terroirs has become one of the most relevant topics nowadays in geosciences [10]. Vineyards are notably one of the land uses, in particular in Mediterranean environments, in which high erosion rates are being recorded [11]. There is a growing awareness of the need to avoid high soil erosion rates and to reduce the transfer of pollutants downstream [12,13]. To meet this goal, new agricultural measures are being applied through the development of new agri-environments with conceptual models of public spending efficiency [14] in the recovery of soil functions and services [15–18]. The occurrence of extreme rainfall events, soil characteristics and in some cases steep slopes contribute to soil degradation. Several studies note that these factors cause soil degradation in vineyards and show how they affect soil surface characteristics [19,20] and can be relevant indicators to classify and analyze actual soil degradation processes in vineyards [13,21–26]. According to this, the most important question to investigate has become the spatial and temporal variability of soil patterns caused by geomorphological dynamics over only a few hectares [27–30].

To enable quantification of these spatially variable parameters, small portable rainfall simulators are useful tools, because they provide information about the detachment, transport and deposition of soil particles. They are the key to understanding soil erosion and hydrological process, and to design strategies to control the non-sustainable soil losses found in vineyards. Several authors have applied these experiments to measure rainfall–runoff processes, splash effect, soil erosion, infiltration, permeability, irrigation or nutrient movement [22,31–48]. However, despite the effort and time invested by researchers in the understanding of soil degradation using rainfall simulations, one of the most important problems is the lack of a standard rainfall simulator for an effective transfer of knowledge and generation of comparable data.

The characteristics of the different rainfall simulators, such as the spatial rainfall distribution, drop sizes and velocities, drop kinetic energy and plot forms and sizes are different among the rainfall simulators applied in the compared studies. In addition, different land covers and different experimental simulations characteristics (rainfall intensities, experimental time or plot sizes) make a successful comparison difficult [49,50]. Moreover, climate is different at the different locations, which means that the rainfall simulators should produce rain of different characteristics. Therefore, it is important to have a fleet of rainfall simulators with diverse rainfall properties as they can all provide required types of experiments that are needed to match the environmental conditions of different regions.

However, a number of publications on rainfall simulations in vineyards asks for one standard methodology to be able to compare the results in different climatic settings and under different management. The data obtained from all the studies of rainfall simulations in vineyards could be of great significance to compare the simulated processes, and could also serve as a source of input- and validation-data for soil erosion modeling and extrapolations to larger scales [51,52]. This could be an important and useful step for a reliable assessment of vulnerability, risk levels and control of soil degradation in European terroirs. These insights can in turn serve as a basis to develop more sustainable management of vineyards around Europe.

Therefore, the aims of this research are: (i) to investigate where, how and why researchers from different wine-growing regions applied rainfall simulations with successful results as a tool to measure soil erosion processes; (ii) to make a qualitative comparison about the general soil erosion processes in European terroirs; (iii) to demonstrate the importance of the development of a standard method for studying soil erosion processes in vineyards, using rainfall simulators and; and (iv) to analyze the key factors that should be taken into account to carry out rainfall simulations.

## 2. Materials and Methods

### 2.1. Study Area

The selected study areas are located in traditional and conventional European wine-growing regions (Figure 1 and Table 1).

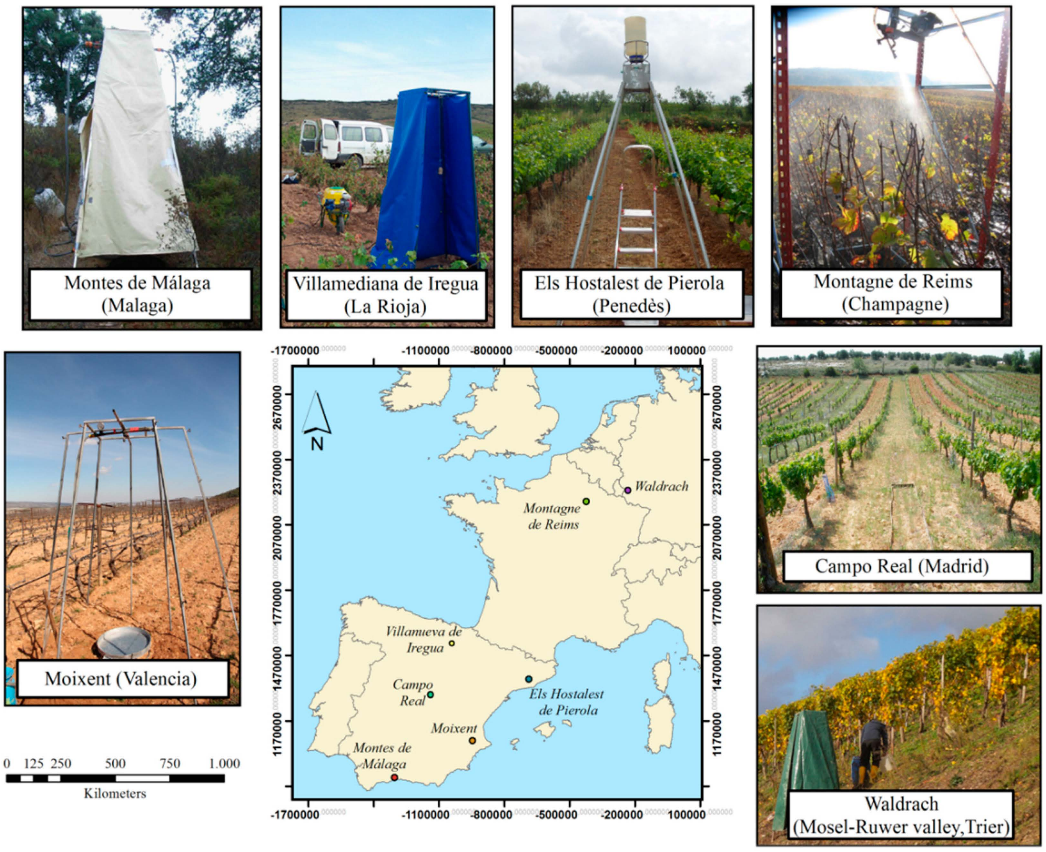


**Figure 1.** Localization of the study areas.

**Table 1.** Study areas with their characteristics.

| **Place** | **Ruwer-Mosel Valley (Trier)** | **Montagne de Reims (Champagne)** | **Montes de Málaga (Málaga)*** | **ElsHostalest de Pierola (Penedès)** | **Moixent (Valencia)** | **Villamedianade Iregua (La Rioja)** | **Campo Real (Madrid)** |
|---|---|---|---|---|---|---|---|
| Clay (%) | 9.4 | 6–12 | - | 10.6 | 8 | 19.9 | 24 |
| Silt (%) | 64.7 | 45–55 | - | 25.8 | 32 | 40.4 | 18 |
| Sand (%) | 26 | 33–45 | - | 63.6 | 60 | 39.9 | 58 |
| SOM[7] | 6.1 | 3.9–8.3 | 2 | 1.2 | 1.01 | 0.9 | 1.7 |
| pH | 7.2 | 8 | - | 8.6 | 7.8 | 8.4 | 8.5 |
| Coordinates (WGS 1984) | 49.74N; 6.75E | 49.16N; 4.12E | 36.76N; −4.39E | 41.59N, 1.77E | 38.78N; 0.87E | 42.26N; 2.23 E | 40.35N; −3.37E |
| Altitude (m.a.s.l.) | 220-250 | 170 | 500 | 330-360 | 550 | 425–450 | 820 |
| Grape variety | *Riesling* | *Pinot noir, Pinot meunier* and *Chardonnay* | *Muscat of Alexandria* | *Parellada, Macabeo, Xarello* and *Chardonnay* | *Monastrell* | *Tempranillo* | *Tempranillo* |
| Soiltillage | Machinery, grass/pruning cover | Machinery, grass/pruning cover (ecological and conventional) | Conventional with animals and ploughing | Machiniery and herbicids. | Ploughing | Terrace (1–2 m height), machiniery, soil tillage and herbicids | Machinery |
| T° ($\bar{x}$)[1] | 9.3 | - | 15.6 | 15 | 14.2 | 14.6 | 14.4 |
| T° (max_$\bar{x}$)[2] | 17.6 | - | - | 31.4 | 25 | 21.1 | 21,1 |
| T° (min_$\bar{x}$)[3] | 1.5 | - | - | 1.5 | 9.2 | 1.2 | 7.9 |
| Pp ($\bar{x}$total)[4] | 765 | 757 | 586.1 | 520 | 420 | 419 | 371 |
| Pp (max_$\bar{x}$)[5] | 71.2 | 72.9 | - | 76.6 | 42 | 75 | 51 |
| Pp (min_$\bar{x}$)[6] | 50.6 | 33.2 | - | 22.6 | 5 | 42.3 | 9 |

1 = Annual average temperatures; 2 = Maximal monthly average temperatures; 3 = Minimal monthly average temperatures; 4 = Average of annual rainfall depth; 5 = Maximal monthly average rainfall depth; 6 = Minimal monthly average rainfall depth; 7 = Soil organic matter; * = Stoniness (52.8%) and porosity (33.3%) were measured for this study.

The area of study in Germany is located close to the village of Waldrach (49.7418N; 6.7524E), which is in the Ruwer-Mosel valley (Rhineland-Palatinate, Germany), a tributary of the Mosel River. These vineyards (with the *Riesling* grape variety) are characterized by conventional management, including soil tillage with machinery and grass/pruning cover. The site is located on steep slopes (25–50%) and the soil is characterized by a high rock fragments percentage on the surface, a silt proportion of 64.7% and a soil organic matter content of 6.1%. Total average annual rainfall is about 780 mm and the annual average temperature is 9.3°C. For this area, Trier and Málaga universities studied the impacts of rainfall and human influences on soil erosion and determined with botanic marks of the graft unions soil loss rates of 3.4 $\text{Mg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$, high geometrical variations of the rills and elevated infiltration [53,54].

In France, the study site is located close to Paris, in the Montagne de Reims (49.16N; 4.12E). Total annual rainfall is similar to the German study area with 757 mm and maximum monthly events of about 72.9 mm. The most used grape varieties are *Pinot noir, Pinot meunier* and *Chardonnay*. In this case, several different soil treatments for the vineyards were applied: grass/pruning cover, plowing, and use of herbicides or without herbicide. Soils are characterized by similar percentage of silts and sands and relativity high soil organic matter (3.9–8.3%). Morvan *et al.* [20] analyzed the impact of different land management on soil in this area using rainfall simulations. They noted that ecological treatments are more effective against soil erosion than conventional management.

For Spain, five study sites were selected. The first one is the Montes de Málaga in Málaga (36.76N; −4.39E). Martínez-Murillo and Ruiz Sinoga [55] analyzed the influence of the soil surface components on these hillslope vineyards with *Muscat of Alexandria* grape variety. This conventional plantation (with handmade and animal works) registers an annual average rainfall of 586.1 mm on soils with a high stoniness (about 52.8%) and low porosity (33.3%).

The second selected study area in Spain is Celler del Roure (38.7833N; 0.87E), in the Les Alcusses valley (Moixent municipality), which is located in Valencia region at 550 m.a.s.l. with a production of *Monastrell* grape variety. Sandy soils (>60% sand) with low soil organic matter content (1.01%) induced soil erosion dynamics in the form of rills and sheet wash. Annual average rainfall is about 420 mm with minimal monthly averages of 5 mm in summer. The rainfall simulations data were produced by the Valencia and Wageningen Universities, following their published methods [26,31–35,56].

Els Hostalest de Pierola (41.59N, 1.77E) in Barcelona province, whose vineyards belong to the Penedès wine-growing region, is the third selected study area. This area (with mainly white varieties such as *Parellada*, *Macabeo*, *Xarello* and *Chardonnay* grape variety production) is characterized by soils with high contents of silt (25.8%) and sands (63.6%) and low soil organic matter (1.2%). Total average annual rainfall is 520 mm and the annual average temperature is 15 °C. Lleida University carried out several studies in that wine region with different topics, mostly related with soil, climatic and phenologic dynamics [57–63].

The fourth selected study area is Villamediana de Iregua (La Rioja) (42.26N; 2.23E). Soils have high clay (19.9%) and sand (39.9%) contents on terraces about 1–2 m height. This traditional vitivicultural area, with *Tempranillo* grape variety production is managed with tillage and herbicides using machinery. Annual average rainfall is 419 mm and annual average temperature is 14.6 °C, with minimum temperatures of 1.2 °C in winter. The Instituto Pirenaico de Ecología (CSIC) and La Rioja University performed several studies on soil erosion, land degradation and wheel tracks signals on these soils [39,64].

Finally, Campo Real in Madrid (40.35N; −3.37E) with organic vineyards of *Tempranillo* grape variety production is the last experimental area. This is a semi-arid area having less than 400 mm of annual rainfall [65–68]. As with the previous study area, soils have high sand content (58%), high clay content (24%) and low soil organic matter (1.2%). These soil characteristics, together with soil tillage with machinery, favor soil degradation processes. The regional extension services (IMIDRA) and researchers from the Autonomous Madrid University studied the effects of different vegetation cover

(*Brachypodium distachyon* and annual barley) between the vine rows as protection measures against the land degradation processes in these vineyards.

### *2.2. Qualitative Comparison with Different Data of Rainfall Simulations in Vineyards*

All the vineyard data from the different research groups were organized in a database in order to homogenize the information. An analysis was done to assess the differences among the experiments due to rainfall simulator design and characteristics, plot size and time intervals for recording runoff during the experiments (Table 2). The results were interpreted taking all parameters into account, which can play an important role in the final observed soil dynamics processes.

The first technical characteristic is the dropper system. In Moixent (Valencia, Spain), Ruwer-Mosel valley (Trier, Germany) and Villamediana de Iregua (La Rioja, Spain), the same nozzle (*Lechler* 460.608) was used. In the other locations, *spraying systems* (Campo Real, Madrid), *Hardy* nozzle (Montes de Málaga, Spain), a dropping system controlled by a water column (Els Hostalest de Pierola, Spain) and a *Teejet* nozzle (Montagne de Reims, France) were the principal applied brand.

The second characteristic was the size and form of the plot. In four rainfall simulations, ring plots with sizes between 0.25 and 0.45 $m^2$ were used (Moixent, Ruwer-Mosel valley, Montes de Málaga and Villamediana de Iregua). In the other locations, the plots were rectangular with different dimensions: 2 $m^2$ in Campo Real, 0.6 $m^2$ in Els Hostalest de Pierola, 0.25 $m^2$ in Montagne de Reims. With respect to the third characteristic, the droppers or nozzle height, there was more uniformity, as they ranged from 2 and 2.5 m above the soil surface.

The last characteristic was the operational method, where several differences were observed. For example, the total duration of the experiments ranged between 15 minutes in the vineyards of Campo Real and 90 minutes in Montagne de Reims, and the time intervals for collecting runoff samples ranged between 1 and 10 minutes.

For more concrete information about the different methods (rainfall intensities, study areas, duration of the experiments, *etc.*), the articles for each research group were also added to Table 2.

In order to homogenize the information, all data of the rainfall simulations experiments (data sheets) were organized into five-minute time steps. However, because some authors used different intervals in different experiments (between 5 and 15 minutes), results must be homogenized, calculating the suspended sediment load (SSL) per hour ($g\cdot m^{2}\cdot h^{-1}$), surface flow ($L\cdot m^{2}\cdot h^{-1}$) and suspended sediment load concentration (SSC in $g\cdot L\cdot m^{2}\cdot h^{-1}$), using:

$$(1) \quad \text{Suspended sediment load (SSL)} = \frac{\frac{g.5\ min^{-1}}{A} x60}{RFt}$$

$$(2) \quad \text{Surface flow} = \frac{\frac{L.5\ min^{-1}}{A} x60}{RFt}$$

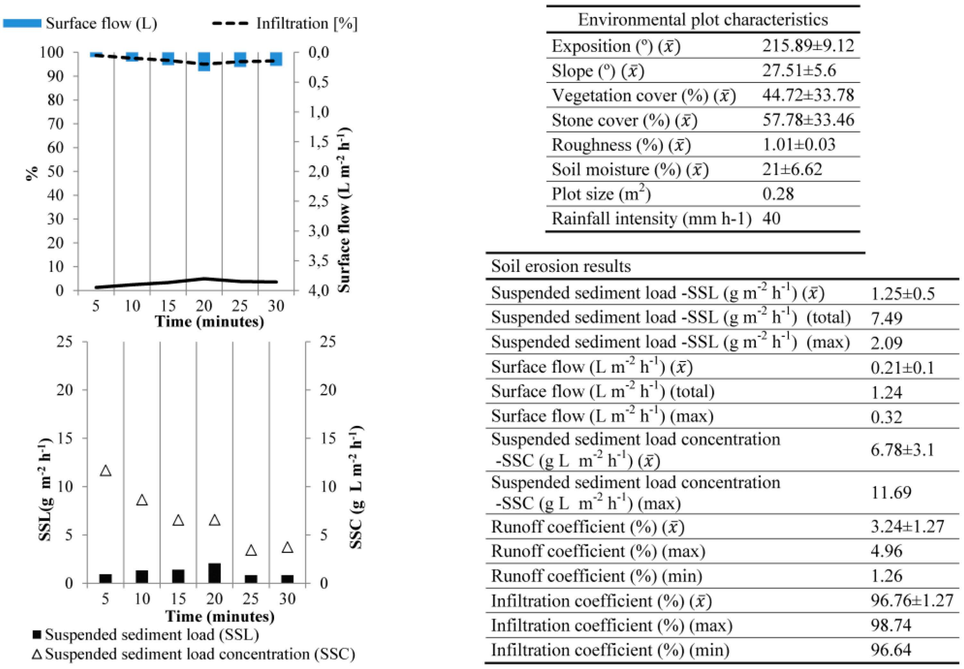
$$(3) \quad \text{Suspended sediment load concentration (SSC)} = \frac{\text{SSL}}{\text{Surface flow}}$$

where $A$ is the area of the rainfall simulator plot and $RFt$ is the duration of the rainfall experiment. After transforming the data, the obtained results were not exactly equals to the values of the published papers, but these calculations were necessary to make the graphics and commentaries similar.

For each site, soil erosion results are presented separately (Figures 2–8). First, bar and point graphs show the averages per intervals of 5 minutes of the suspended sediment load (SSL in $g\cdot m^{-2}\cdot h^{-1}$) and the suspended sediment load concentration (SSC in $g\cdot L\cdot m^{-2}\cdot h^{-1}$). The second graphic presents the surface flow ($L\cdot m^{-2}\cdot h^{-1}$), runoff (%) and infiltration (%) coefficients. Furthermore, tables for each study site were added to show: (i) the previous environmental plot characteristics during the experiments; and (ii) the averages ($\overline{x}$), totals, maximum (max) and minimum (min) values of the SSL, surface flow, SSC, runoff coefficient (%) and infiltration coefficient (%).

**Table 2.** Rainfall simulators and methods.

| | **Flow Control** | **Nozzle** | **Electricbilge Pump** | | **Plot** | | | **Current Method** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manometer Pressure (bar or kg· cm$^2$) | Type | Head of the Pump (m) | Voltage (V) | Area (m$^2$) | Form | Height (m) | Total Time (min) | Interval (min) | Investigation |
| Ruwer-Mosel valley Moixent | 0.2 bars | *Lechler* 460.608 | 4.5 | 12 | 0.28 | Ring | 2 | 30–60 | 5 | Ruwer-Mosel valley: [53,54]. Alforins: [26,56] |
| Campo Real | 1.5 ± 0.2 kg· cm$^{-2}$ | Spraying systems 1/3 HH 35 W. Two nozzles separated 1.5 m apart | 7 | 6.5 | 2 | Rectangle | 2 | 15 | 1 | [65–68] |
| Montes de Málaga | - | *Hardi* 1553-20 | - | - | 0.28 | Ring | 2 | 60 | 5 | [55] |
| Villamediana de Iregua | 20 bars | *Lechler* 460.728 (<50 mm· h$^{-1}$)<br>*Lechler* 460.608 (50–70 mm· h$^{-1}$)<br>*Lechler* 460.880 (70 mm· h$^{-1}$) | - | - | 0.45 | Ring | 2.5 | 30–45 | 3–5 | [39,64] |
| ElsHostalest de Pierola | 2.5 mm diameter drops of deionised water freely | Rainfall intensity was controlled by modifying the water column above the droppers, using an inverted Mariotte's bottle | - | - | 0.6 | Rectangle | 2.5 | 60 | 10 | [57–63] |
| Montagne de Reims | 2-3 bars | *Teejet* 6501-<br>*Teejet* 6508 | Max. 2.5 m | 220 | 0.25 | Square | 2.5 | 90 | Mostly 10 min | [20] |



| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 215.89±9.12 |
| Slope (°) ($\bar{x}$) | 27.51±5.6 |
| Vegetation cover (%) ($\bar{x}$) | 44.72±33.78 |
| Stone cover (%) ($\bar{x}$) | 57.78±33.46 |
| Roughness (%) ($\bar{x}$) | 1.01±0.03 |
| Soil moisture (%) ($\bar{x}$) | 21±6.62 |
| Plot size (m$^2$) | 0.28 |
| Rainfall intensity (mm h-1) | 40 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 1.25±0.5 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (total) | 7.49 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (max) | 2.09 |
| Surface flow (L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 0.21±0.1 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (total) | 1.24 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (max) | 0.32 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 6.78±3.1 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) (max) | 11.69 |
| Runoff coefficient (%) ($\bar{x}$) | 3.24±1.27 |
| Runoff coefficient (%) (max) | 4.96 |
| Runoff coefficient (%) (min) | 1.26 |
| Infiltration coefficient (%) ($\bar{x}$) | 96.76±1.27 |
| Infiltration coefficient (%) (max) | 98.74 |
| Infiltration coefficient (%) (min) | 96.64 |

**Figure 2.** Rainfall simulations in Ruwer-Mosel valley (Trier, Germany).

To qualitatively compare the initial soil erosion processes with the different rainfall simulators characteristics and plot sizes, a final table with the results of the first 15 minutes of each rainfall simulations was presented. This time was chosen, because it represents the minimum duration of all the experiments.

Finally, a Spearman correlation test was performed to detect which factor shows the best trend (with the increasing or decreasing) with the SSL, surface flow and SSC (averages and maximum).

## 3. Results

### 3.1. *Ruwer-Mosel Valley (Trier, Germany)*

Rainfall simulations at the Ruwer-Mosel valley were applied to study soil erosion processes before, during and after the vintage in conventional vineyards. Four rainfall simulations in August (2008) and five between September and December (2013) were performed. The experiments were done between August and September and coincided with tillage practices before the harvest. The rest of the simulations were done after the harvest, coinciding with the period of decreasing rainfall amounts and temperatures. Results of these rainfall simulation experiments were obtained with a rainfall intensity of 40 $\text{mm} \cdot \text{h}^{-1}$.

The plots were characterized by steep slopes (27.5 ± 5.6°), with high vegetation cover (44.7 ± 33.8%) and high stone cover (57.8 ± 33.5%). The aim to this study was to measure the impact of rainfall and tillage practices on the soil before, during and after the harvest.

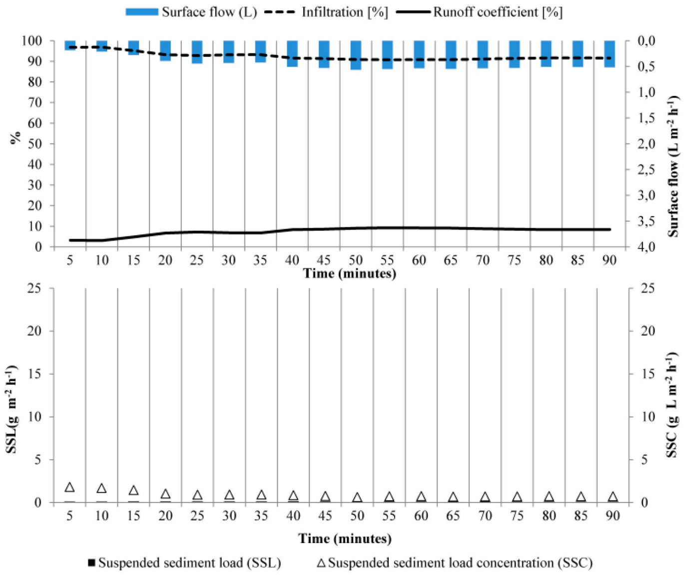
The average SSL was 1.25 ± 0.05 $\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ with a maximum value of 2.09 $\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ during the interval of 15–20 minutes. Surface flow was 0.21 ± 0.1 $\text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ with a maximum value of 0.32 $\text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$. SSC showed higher values at the beginning of the experiment than at the end of the simulation, with an average of 6.8 ± 3.1 $\text{g} \cdot \text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ and maximum of 11.7 $\text{g} \cdot \text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$.

Finally, high infiltration (96.7 ± 1.3%) and low runoff coefficients (3.2 ± 1.3%) were observed in all experiments.

### 3.2. Montagne de Reims (Champagne, France)

Rainfall simulations in Montage de Reims were applied in vineyards with three commonly used cultivation practices in Champagne: bare soil (1), bark and vine pruning (3), and grass cover (8). The goal was to quantify the influence of cultivation practices in the inter-row of vines and to determine the influence of the density of grass cover on soil loss and surface runoff. Twelve rainfall simulations were carried out during about 90 minutes with different rainfall intensities ranging between 20 and 76 mm· $h^{-1}$ (Figure 3).

Environmental characteristics included a slope of 5.2 ± 0.8°, a vegetation cover of 44.9 ± 43.2% and soil moisture of 19.4 ± 0.6%. Results were highly heterogeneous depending on the cultivation practice. Average SSL was 0.13 ± 0.1 g· $m^{-2}$· $h^{-1}$ with maximal values of 0.15 g· $m^{-2}$· $h^{-1}$. Average surface flow showed values of 0.15 L· $m^{-2}$· $h^{-1}$. 0.94 ± 0.003 g· L· $m^{-2}$· $h^{-1}$ was the average of the suspended sediment load concentration. Finally, in this case, we also observed high average infiltration (92.5 ± 2%) and low average runoff coefficient (7.5 ± 2%).



| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 180±0 |
| Slope (°) ($\bar{x}$) | 5.2±0.8 |
| Vegetation cover (%) ($\bar{x}$) | 44.9±43.2 |
| Stone cover (%) ($\bar{x}$) | - |
| Roughness (%) ($\bar{x}$) | - |
| Soil moisture (%) ($\bar{x}$) | 19.4±0.6 |
| Plot size ($m^2$) | 0.25 |
| Rainfall intensity (mm $h^{-1}$) | 20-76 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 0.13±0.01 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (total) | 2.33 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (max) | 0.15 |
| Surface flow (L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 0.15±0.04 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (total) | 2.74 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (max) | 0.19 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 0.94±0.003 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) (max) | 1.82 |
| Runoff coefficient (%) ($\bar{x}$) | 7.51±2 |
| Runoff coefficient (%) (max) | 9.27 |
| Runoff coefficient (%) (min) | 3.12 |
| Infiltration coefficient (%) ($\bar{x}$) | 92.49±2 |
| Infiltration coefficient (%) (max) | 96.88 |
| Infiltration coefficient (%) (min) | 95.2 |

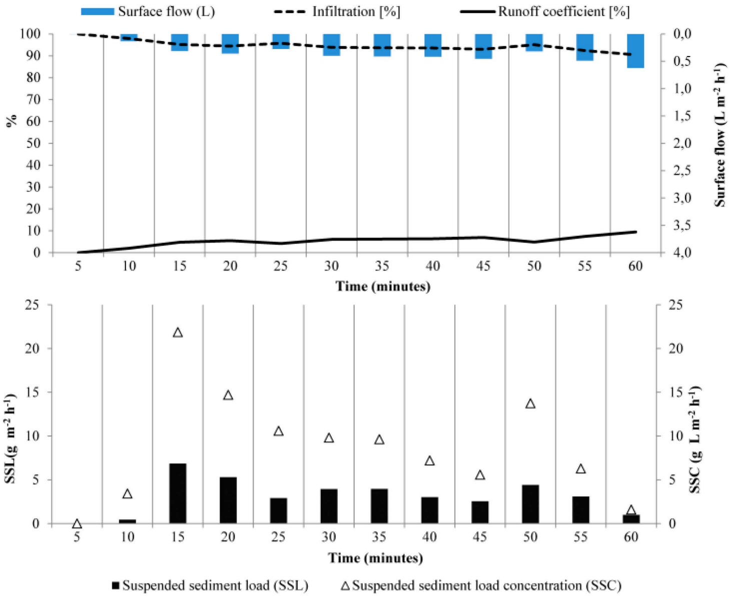
**Figure 3.** Rainfall simulations in Montagne de Reims (Champagne, France).

### 3.3. Spain

#### 3.3.1. Montes de Málaga

The aim of this study was to compare rainfall impact on soil without vegetation cover and high stoniness. The rainfall simulations in Montes de Málaga were carried out in June (2003) in three different locations along a hillslope of 23° in a conventional vineyard (Figure 4): at the top (2), middle (2) and foot (2) slope. Two replications were done at each location. All experiments were carried out with 63–66 mm· $h^{-1}$ rainfall intensity with a duration of 60 minutes.

No vegetation cover and high stoniness (52.8%) characterized the plot. The average SSL was 3.13 ± 2.69 g· $m^{-2}$· $h^{-1}$ with maximum values of 6.85 g· $m^{-2}$· $h^{-1}$. Surface flow was 0.35 ± 0.15 L· $m^{-2}$· $h^{-1}$ (with maximum values of 0.62 L· $m^{-2}$· $h^{-1}$). The results gave rise to high SSC, (8.71 ± 0.56 g· L· $m^{-2}$· $h^{-1}$), which reached 21.88 g· L· $m^{-2}$· $h^{-1}$. Finally, runoff coefficients of 5.4 ± 2.5% and 94.6 ± 2.5% of infiltration were measured.



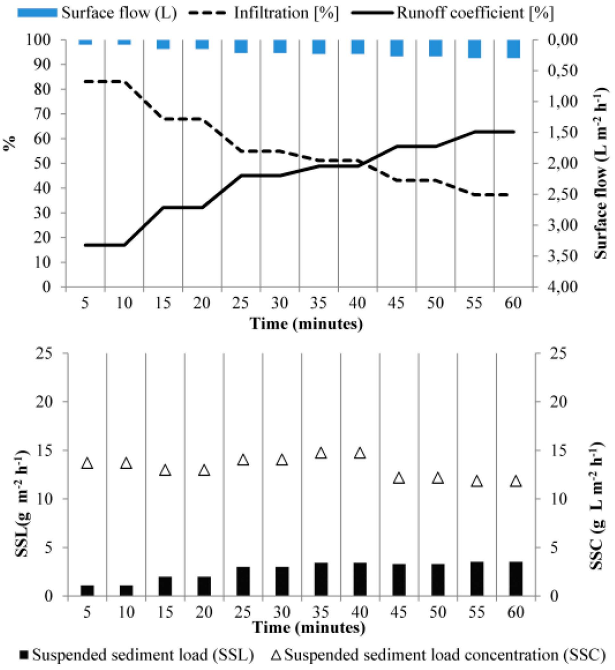
| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 180±0 |
| Slope (°) ($\bar{x}$) | 23±0 |
| Vegetation cover (%) ($\bar{x}$) | 0±0 |
| Stone cover (%) ($\bar{x}$) | 52.8±0 |
| Roughness (%) ($\bar{x}$) | - |
| Soil moisture (%) ($\bar{x}$) | - |
| Plot size (m$^{2}$) | 0.28 |
| Rainfall intensity (mm h$^{-1}$) | 63-66 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 3.13±2.69 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (total) | 37.52 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (max) | 6.85 |
| Surface flow (L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 0.35±0.15 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (total) | 4.21 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (max) | 0.62 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 8.71±0.56 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) (max) | 21.88 |
| Runoff coefficient (%) ($\bar{x}$) | 5.37±2.5 |
| Runoff coefficient (%) (max) | 9.54 |
| Runoff coefficient (%) (min) | 0.04 |
| Infiltration coefficient (%) ($\bar{x}$) | 94.63±2.5 |
| Infiltration coefficient (%) (max) | 99.96 |
| Infiltration coefficient (%) (min) | 95.21 |

**Figure 4.** Rainfall simulations in Montes de Málaga (Andalucía, Spain).

### 3.3.2. Els Hostalest de Pierola (Penedès)

The aim of the simulations was to evaluate the variability of infiltration along the slope due to disturbances created by land leveling operations. The simulation carried out in this experiment was quite similar to that performed in Málaga: six rainfall simulations (Figure 5) on three different points along the slope (top, middle and foot), with two replications in each of them. The simulations were done in June (2010) with a rainfall intensity ranging between 48 and 70 mm· h$^{-1}$, with a duration of 60 minutes, although after 40 minutes a constant runoff volume was reached.



| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 180±0 |
| Slope (°) ($\bar{x}$) | 9.83±4.08 |
| Vegetation cover (%) ($\bar{x}$) | 8.67±21.23 |
| Stone cover (%) ($\bar{x}$) | 11±1.55 |
| Roughness (%) ($\bar{x}$) | 1.67±0.82 |
| Soil moisture (%) ($\bar{x}$) | 23.1±1.23 |
| Plot size (m$^{2}$) | 0.6 |
| Rainfall intensity (mm h$^{-1}$) | 48-70 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 2.73±0.86 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (total) | 32.78 |
| Suspended sediment load -SSL (g m$^{-2}$ h$^{-1}$) (max) | 3.54 |
| Surface flow (L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 0.21±0.06 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (total) | 2.50 |
| Surface flow (L m$^{-2}$ h$^{-1}$) (max) | 2.73 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) ($\bar{x}$) | 13.27±0.6 |
| Suspended sediment load concentration -SSC (g L m$^{-2}$ h$^{-1}$) (max) | 14.77 |
| Runoff coefficient (%) ($\bar{x}$) | 43.75±16.04 |
| Runoff coefficient (%) (max) | 62.71 |
| Runoff coefficient (%) (min) | 16.92 |
| Infiltration coefficient (%) ($\bar{x}$) | 56.25±16.04 |
| Infiltration coefficient (%) (max) | 83.08 |
| Infiltration coefficient (%) (min) | 37.29 |

**Figure 5.** Rainfall simulations in Els Hostalest de Pierola (Penedès, Spain).

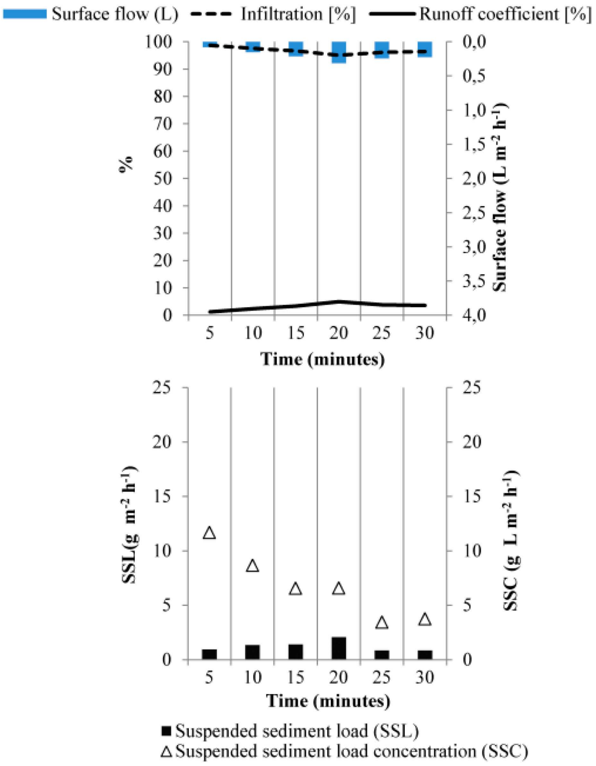
The slope of the study area was 9.8 ± 4° with scarce soil cover (vegetation cover of 8.7 ± 21.2% and stone cover of 11 ± 1.6%). Soil moisture was 23.1 ± 11.2% and roughness was 1.7 ± 0.8%.

The average soil loss was 2.73 ± 0.86 g· $m^{-2}$· $h^{-1}$ with maximum values of 3.54 g· $m^{-2}$· $h^{-1}$. Surface flow was 0.21 ± 0.06 L· $m^{-2}$· $h^{-1}$. These results meant suspended sediment load concentrations of 13.27±0.6 g· L· $m^{-2}$· $h^{-1}$, with the highest values being14.77 g· L· $m^{-2}$· $h^{-1}$.

Finally, runoff coefficient showed an average value of 43.8 ± 16% with a maximum value of 62.7% and infiltration averaged 56.3 ± 16% with values of up to 80%.

### 3.3.3. Moixent (Valencia, Spain)

The aim of this study was to measure the immediate effect of barley straw mulch on soil erosion and to detect the runoff processes. Sixteen rainfall experiments during the first days of July 2015 were conducted (Figure 6). Similar to the vineyard in Ruwer-Mosel valley, the experiment applied in this Mediterranean vineyard consisted of thirty minutes duration and intervals of five minutes to collect samples. This period corresponded with the driest period of the summer and before the vintage. Rainfall intensity was 40 mm· $h^{-1}$.



| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 180±0 |
| Slope (°) ($\bar{x}$) | 2.5±1.03 |
| Vegetation cover (%) ($\bar{x}$) | 1.5±2.03 |
| Stone cover (%) ($\bar{x}$) | 21.06±3.75 |
| Roughness (%) ($\bar{x}$) | 5.38±2.5 |
| Soil moisture (%) ($\bar{x}$) | 4.6±0.67 |
| Plot size ($m^2$) | 0.28 |
| Rainfall intensity (mm $h^{-1}$) | 40 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 6.86±7.5 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (total) | 41.18 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (max) | 16.36 |
| Surface flow (L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 1.17±1.4 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (total) | 7.04 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (max) | 3.35 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 6.17±0.9 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) (max) | 6.91 |
| Runoff coefficient (%) ($\bar{x}$) | 18.33±21.3 |
| Runoff coefficient (%) (max) | 52.34 |
| Runoff coefficient (%) (min) | 0 |
| Infiltration coefficient (%) ($\bar{x}$) | 81.67±21.3 |
| Infiltration coefficient (%) (max) | 100 |
| Infiltration coefficient (%) (min) | 47.66 |

**Figure 6.** Rainfall simulations in Moixent (Valencia, Spain).

All experiments were carried out on lands with low slopes (2.5 ± 1.03°), low vegetation cover (1.5 ± 2%) and low stone cover (21.1 ± 3.8%).

At the beginning, during the first 10 minutes, any runoff was noted. After that time, the average SSL was 6.86 ± 7.5 g· $m^{-2}$· $h^{-1}$ with a maximum of 16.36 g· $m^{-2}$· $h^{-1}$. The average surface flow was 1.17 ± 1.4 L· $m^{-2}$· $h^{-1}$ with a maximum value of 3.35 L· $m^{-2}$· $h^{-1}$. This resulted in an average SSC of 6.2 ± 0.9 g· L· $m^{-2}$· $h^{-1}$ with a maximum of 6.91 g· L· $m^{-2}$· $h^{-1}$.

In this study, in most cases, high infiltration rates (81.7 ± 21.3%) were observed. However, on a few occasions, runoff coefficients higher than 50% were also registered.

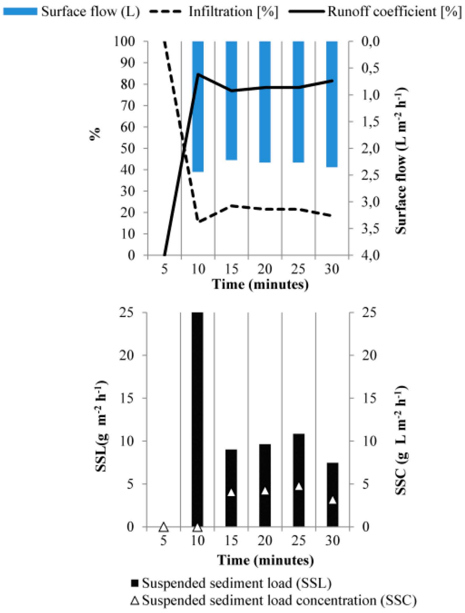
### 3.3.4. Villamediana de Iregua (La Rioja)

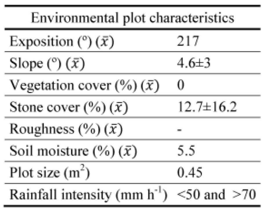
The goal of the rainfall simulations carried out in La Rioja was to measure the response of the soil to the effects of wheel tracks. Twenty-nine rainfall simulations were carried out in September, coinciding with the lowest soil moisture values (5–6%). The simulations had a rainfall intensity between <50 and >70 $\text{mm}\cdot\text{h}^{-1}$.

There was no vegetation cover, while a stone cover of 12.7 ± 16.2% was noted. The slope of the plots was 4.6 ± 3° and with a SSW aspect.

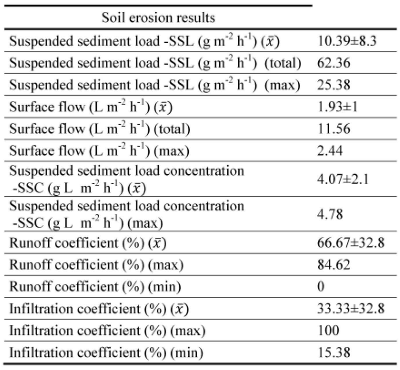
Results did not show any surface flow and soil loss during the first five minutes of the experiment (Figure 7). However, after that time period, the average soil loss was 10.4 ± 8.3 $\text{g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ with a maximum of 25.4 $\text{g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$. With respect to surface flow, 1.9 ± 1 $\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ (max. of 2.4 $\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$) was observed. As a result, a suspended sediment load concentration of 4.1 ± 2.1 $\text{g}\cdot\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ was obtained.

The experiments showed high variation in the average runoff coefficient (66.7 ± 32.8%) and infiltration (33.3 ± 32.8%).





| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 217 |
| Slope (°) ($\bar{x}$) | 4.6±3 |
| Vegetation cover (%) ($\bar{x}$) | 0 |
| Stone cover (%) ($\bar{x}$) | 12.7±16.2 |
| Roughness (%) ($\bar{x}$) | - |
| Soil moisture (%) ($\bar{x}$) | 5.5 |
| Plot size ($m^2$) | 0.45 |
| Rainfall intensity (mm $h^{-1}$) | <50 and >70 |



| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 10.39±8.3 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (total) | 62.36 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (max) | 25.38 |
| Surface flow (L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 1.93±1 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (total) | 11.56 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (max) | 2.44 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 4.07±2.1 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) (max) | 4.78 |
| Runoff coefficient (%) ($\bar{x}$) | 66.67±32.8 |
| Runoff coefficient (%) (max) | 84.62 |
| Runoff coefficient (%) (min) | 0 |
| Infiltration coefficient (%) ($\bar{x}$) | 33.33±32.8 |
| Infiltration coefficient (%) (max) | 100 |
| Infiltration coefficient (%) (min) | 15.38 |

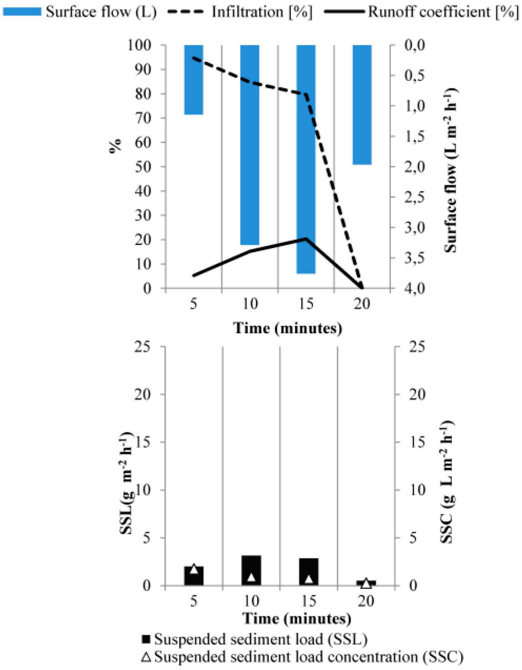
**Figure 7.** Rainfall simulations in Villamediana de Iregua (La Rioja, Spain).

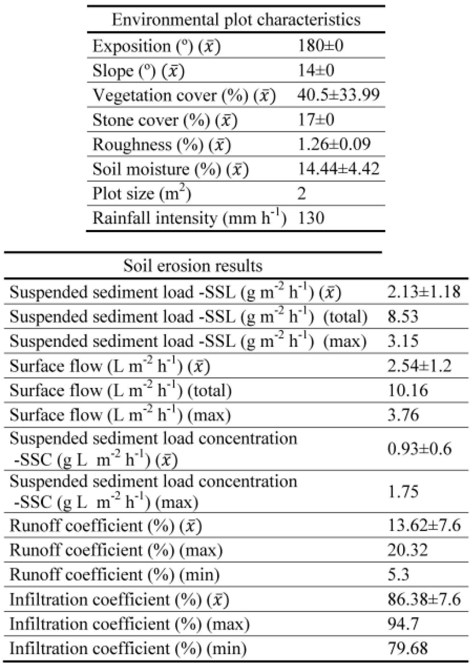
### 3.3.5. Campo Real (Madrid)

Nine rainfall simulations were run on test plots with different land managements: (i) three with conventional tillage with tractors; (ii) three with secondary vegetation cover of *Brachypodium distachyon*; and (iii) three with annual barley (*Hordeum vulgare L.*). The experiments were conducted in summer after the spring soil tillage and in autumn before the fall soil tillage.The rainfall simulation durations were 15 minutes with intervals of one minute. Furthermore, measurements were also performed between 15 and 20 minutes to record the possible remaining runoff and soil loss after rainfall ended (inertia). Rainfall intensity was 130 $\text{mm}\cdot\text{h}^{-1}$.

Other envirommental plot characteristics during the experiments were 14° slope, 40.5 ± 33.4% average vegetation cover and 17% stone cover.

Results (Figure 8) showed an average SSL of 2.13 ± 1.18 $\text{g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ with a maximum of 3.15 $\text{g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$. Surface flow average was 2.54 ± 1 $\text{g}\cdot\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ with high values of 3.76 $\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$. An average sediment concentration of 0.93 ± 0.6 $\text{g}\cdot\text{L}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$ was noted. High infiltration (86.4 ± 7.6%) and a low runoff coefficient (13.6 ± 7.6%) were also observed.





| Environmental plot characteristics | |
|---|---|
| Exposition (°) ($\bar{x}$) | 180±0 |
| Slope (°) ($\bar{x}$) | 14±0 |
| Vegetation cover (%) ($\bar{x}$) | 40.5±33.99 |
| Stone cover (%) ($\bar{x}$) | 17±0 |
| Roughness (%) ($\bar{x}$) | 1.26±0.09 |
| Soil moisture (%) ($\bar{x}$) | 14.44±4.42 |
| Plot size ($m^2$) | 2 |
| Rainfall intensity (mm $h^{-1}$) | 130 |

| Soil erosion results | |
|---|---|
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 2.13±1.18 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (total) | 8.53 |
| Suspended sediment load -SSL (g $m^{-2}$ $h^{-1}$) (max) | 3.15 |
| Surface flow (L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 2.54±1.2 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (total) | 10.16 |
| Surface flow (L $m^{-2}$ $h^{-1}$) (max) | 3.76 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) ($\bar{x}$) | 0.93±0.6 |
| Suspended sediment load concentration -SSC (g L $m^{-2}$ $h^{-1}$) (max) | 1.75 |
| Runoff coefficient (%) ($\bar{x}$) | 13.62±7.6 |
| Runoff coefficient (%) (max) | 20.32 |
| Runoff coefficient (%) (min) | 5.3 |
| Infiltration coefficient (%) ($\bar{x}$) | 86.38±7.6 |
| Infiltration coefficient (%) (max) | 94.7 |
| Infiltration coefficient (%) (min) | 79.68 |

**Figure 8.** Rainfall simulations in Campo Real (Madrid, Spain).

### *3.4. Final Comparison*

Different results were observed during the first 15 minutes of each rainfall simulation experiment (Table 3). High soil losses were observed in Montes de Málaga and Villamediana de Iregua (2.44 and 2.58 g· $m^{-2}$· $h^{-1}$, respectively). However, Waldrach, Moixent and Montagne de Reims obtained low rates due to the high infiltration coefficients (near 100%). Finally, high values of runoff were observed for Villamediana de Iregua and Els Hostalest de Pierola (between 22 and 54%).

Finally, a Spearman's rank correlation coefficient was calculated for these data to analyze the possible relationship between independent (plot, rainfall intensity and environmental conditions) and dependent (SSL, SF, SSC, RC, and IC) variables (Table 4).

First, it can observe that the plot size obtained a correlation between 0.519 and 0.593 with the surface flow (SF) and the runoff coefficient. Furthermore, correlation between an increase of the SSL and an increase in runoff and a decrease in infiltration were noted (0.607 and −0.607, respectively). SF and SSC showed relationships with a decrease of the soil moisture inside the plot, −0.522 and −0.725, respectively. Finally, with a decrease in the percentage of slope and vegetation cover (−0.613 and −0.667), an increase of SSC was noted.

**Table 3.** Rainfall simulation results during the first 15 minutes.

| | **Waldrach (Mosel-Ruwer, Trier)** | **Montagne de Reims (Champagne)** | **Montes de Málaga (Málaga)** | **Els Hostalest de Pierola (Penedés)** | **Moixent (Valencia)** | **Villamediana de Iregua (La Rioja)** | **Campo Real (Madrid)** |
|---|---|---|---|---|---|---|---|
| RI[1] | 0.9 ± 1.4 | 0.77 ± 0.1 | 1.83 ± 0 | 0.29 ± 0 | 0.9 ± 1.4 | 0.65 ± 0 | 10.29 ± 0.9 |
| Plot[2] | 0.28 | 0.25 | 0.28 | 0.6 | 0.28 | 0.45 | 2 |
| SSL[3] | 0.17 ± 0 | 0.12 ± 0.01 | 2.44 ± 3.8 | 1.4 ± 0.5 | 0.11 ± 0.2 | 2.58 ± 2.9 | 1.33 ± 0.3 |
| SF[4] | 0.15 ± 0.1 | 0.08 ± 0.1 | 0.15 ± 1 | 0.1 ± 0 | 0.12 ± 0.2 | 1.56 ± 1.6 | 1.37 ± 0.7 |
| SSC[5] | 8.97 ± 2.6 | 1.65 ± 0.2 | 8.44 ± 11.8 | 13.48 ± 0.4 | 2.15 ± 3.8 | 1.35 ± 2.3 | 1.15 ± 0.5 |
| RC[6] | 2.3 ± 1.1 | 3.7 ± 0.9 | 2.3 ± 2.4 | 22 ± 8.8 | 2 ± 3.3 | 53.9 ± 46.8 | 13.6 ± 7.6 |
| IC[7] | 97.7 ± 1.1 | 96.3 ± 0.9 | 97.7 ± 2.4 | 78 ± 8.8 | 98.1 ± 3.3 | 46.2 ± 46.8 | 86.4 ± 7.6 |

1 = Rainfall intensity L· 5· $min^{-1}$; 2 = Plot size ($m^2$); 3 = Suspended sediment load (g· $m^{-2}$· $h^{-1}$); 4 = Surface flow (L· $m^{-2}$· $h^{-1}$); 5 = Suspended sediment load concentration (g· L· $m^{-2}$· $h^{-1}$); 6 = Runoff coefficient (%); 7 = Infiltration coefficient (%).

**Table 4.** Spearman correlation coefficient of the whole dataset.

| | SSL3 | SF4 | SSC5 | RC6 | IC7 | Slope | Vegetation cover (%) | Stone cover (%) | Roughness (%) | Soil moisture (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| RI$^1$ | −0.18 | 0.324 | −0.36 | −0.541 | 0.541 | 0.227 | 0.338 | 0.391 | −0.026 | −0.426 |
| Plot$^2$ | 0.482 | 0.519 | −0.185 | 0.593 | −0.593 | −0.449 | −0.368 | −0.823 | 0.395 | 0.044 |
| SSL$^3$ | - | 0.536 | −0.036 | 0.607 | −0.607 | −0.126 | −0.406 | −0.523 | −0.051 | 0.232 |
| SF$^4$ | 0.536 | - | −0.464 | 0.321 | −0.321 | −0.216 | −0.464 | −0.252 | 0.051 | −0.522 |
| SSC$^5$ | −0.036 | −0.464 | - | 0.179 | −0.179 | −0.613 | −0.667 | −0.432 | 0.41 | −0.725 |
| RC$^6$ | 0.607 | 0.321 | 0.179 | - | 0.321 | 0.018 | −0.116 | −0.018 | 0.205 | 0.406 |
| IC$^7$ | 0.541 | −0.593 | −0.607 | -0.321 | - | −0.018 | 0.116 | 0.018 | −0.205 | −0.406 |

1 = Rainfall intensity $L \cdot 5\ min^{-1}$; 2 = Plot size ($m^2$); 3 = Suspended sediment load ($g \cdot m^{-2} \cdot h^{-1}$); 4 = Surface flow ($L \cdot m^{-2} \cdot h^{-1}$); 5 = Suspended sediment load concentration ($g \cdot L \cdot m^{-2} \cdot h^{-1}$); 6 = Runoff coefficient (%); 7 = Infiltration coefficient (%); Grey colors show the highest correlations of the whole dataset.

## 4. Discussions

Different questions arose referring to the representativeness of rainfall intensity used in the experiments, the influence of the plot size on soil losses and runoff, or the duration of the experiments. It was also observed that there is a high variability in soil detached in each experiment, which ranged from an average value of 0.13 $g \cdot m^{-2} \cdot h^{-1}$ in Montagne de Reims (Champagne, France) to 10.4 $g \cdot m^{-2} \cdot h^{-1}$ in Villamediana de Iregua (La Rioja, Spain), but with maximum soil loss up to 25 $g \cdot m^{-2} \cdot h^{-1}$ (Villamediana de Iregua, La Rioja). The average surface flow was between 0.21 $L \cdot m^{-2} \cdot h^{-1}$ at Ruwer-Mosel valley (Trier, Germany) and 1.93 $L \cdot m^{-2} \cdot h^{-1}$ at Villamediana de Iregua (La Rioja, Spain). Differences were observed for the values of SSC. Els Hostalest de Pierola (Penedès, Spain) showed high values (13.3 $g \cdot L \cdot m^{-2} \cdot h^{-1}$). The lowest results were found in Campo Real (Madrid, Spain) and in Montagne de Reims with (Champagne, France) with 0.9 $g \cdot L \cdot m^{-2} \cdot h^{-1}$, although they applied high rainfall intensities.

The average runoff coefficient ranged between 3.24% (Ruwer-Mosel valley, Trier) and 66.7% (Villamediana de Iregua, La Rioja), with a maximum value of 84.6% (Villamediana de Iregua, La Rioja). This is especially important in areas of water scarcity.

After understanding the context of the rainfall simulation experiments of each investigation group (rainfall simulators, methods and study areas), homogenizing their data sheets in intervals of five minutes, and transforming all values into $m^2 \cdot h^{-1}$, the problematic of soil erosion processes in European vineyards has been observed.

The experiments carried out under different soil tillage conditions and those carried out with different soil covers allowed us to confirm not only the effect of cover to reduce soil erosion [20], but also the utility of using rainfall simulations to evaluate these effects [39,57,60,61,64,66]. Apart from these findings, one important question for the general discussion has not yet been clearly answered: how representative are the data for a general diagnostic about the most sustainable practices in European vineyards? Three causes for this problem could be proposed.

First, how many replicates must be done and where should the experiments be performed in an experimental area? High standard deviations in all experiments and an elevated variability of the trends have been shown. In many cases, runoff coefficients did not show a clear trend to delimit this parameter. Therefore, it may be important to carry out different repetitions or to increase the duration until a constant steady rate of runoff and suspended sediment load is achieved.

Second, the variability of soil surface components and soil tillage practices were determinant too. When and where should we conduct rainfall simulations: (i) before, during or after the vintage? (ii) On the top, middle or foot slope? (iii) In the rows or in the inter-rows? (iv) Which environmental characteristics must be considered on the plots? These responses would be possible: (i) to characterize at least all the different surface components (and their spatial and temporal variability during the year); (ii) to study with soil analysis if there are differences between the different parts of the slope and in the rows or inter-rows; and (iii) to control exactly for the work schedule of the vine-growers.

Third, we have observed that after applying different rainfall simulators (drop sizes and velocities, drop kinetic energy, plot forms and sizes, field of application, methodologies, *etc.*), homogenizing the intervals of the rainfall and understanding the concrete specifications from each study area, it would be difficult directly to conduct any quantitative diagnostics and comparisons. With the Spearman coefficient, for example, correlations between rainfall intensity and plot size were noted. Therefore, as Iserloh *et al.* observed [49,50], there is influence between the results and the technical characteristics of the rainfall simulators. It is clear that the most important reason for this study is to demonstrate the necessity of a standard rainfall simulator and methodology.

In the future, following this investigation, it is necessary to: (i) make quantitative analyses and comparisons between different study areas; (ii) calculate how many simulations and under which environmental and human conditions must be appropriated to develop rainfall simulation campaigns; (iii) spend time recollecting information, sampling methods and data treatments; and (iv) avoid interpretation errors and information losses after calculating averages and grouping the different intervals.

## 5. Conclusions

This collection of rainfall simulations in different contexts offers a wide range of aspects that can be analyzed concerning the magnitude of soil erosion processes in European wine-growing areas. The results shown in these rainfall simulation experiments allowed us to confirm that due to soil characteristics in which the experiments were done: (i) high infiltration and low runoff coefficients may be recorded, as well as the dynamic within the rainfall; and (ii) surface and sub-surface flow dynamics controlled the time at which runoff started and total runoff recorded; however, (iii) higher runoff rates have been indicated in other studies in the same vitivinicultural areas, when soil have higher silt contents. In addition to soil characteristics, the rainfall intensity and duration were additional control factors.

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