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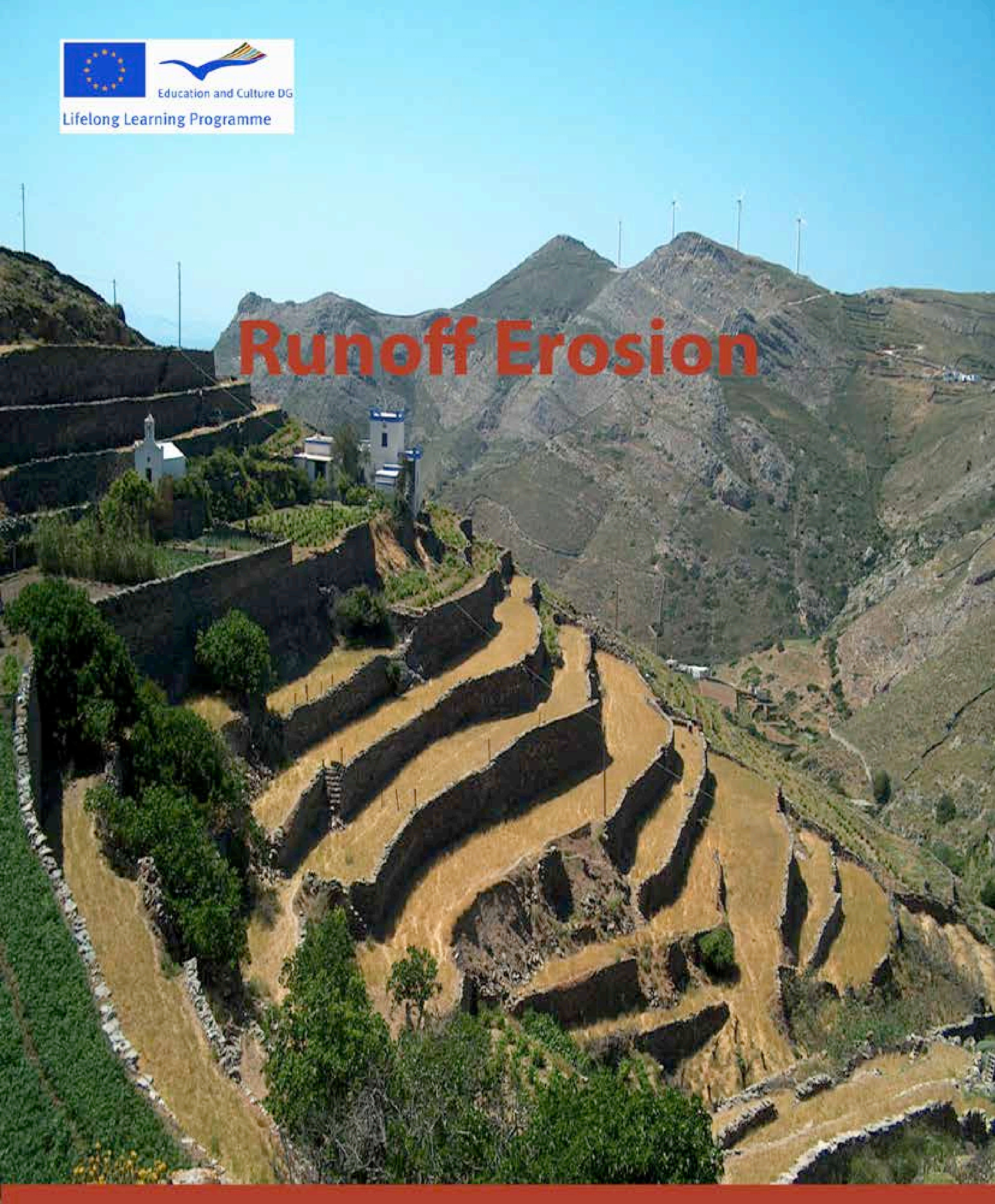

Runoff Erosion

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PART II - CASE STUDIES

CASE STUDY 6: RUNOFF AND SOIL LOSS FROM STEEP SLOPING VINEYARDS IN THE DOURO VALLEY, PORTUGAL: RATES AND FSACTYORS

Tomás de Figueiredo, Jean Poesen, Alfredo Gonçalves Ferreira & Dionísio Gonçalves

1. INTRODUCTION

Some of the most renowned vineyard regions in the world are located in mountain or sloping land, and they very much contrast with flat or gentle slope viticulture (Unwin, 1996; Pérez Verdú & Jofre, 2007; Damásio et al., 2010). The high potential erosion risk prevailing in such topographic conditions has for long been tackled with traditional soil conservation structures, as it is the case of dry-stone walled terraces (e. g. the Douro region, NE Portugal, or the Priorat region, NE Spain), which depended on the availability of cheap labour for constructing and maintaining those structures. Furthermore, with crop management operations manually performed, traditional vine plantation systems required high permanent labour inputs (Bianchi-de-Aguiar, 1987; Guimaraens & Magalhães, 2006; Pérez Verdú & Jofre, 2007; Martinez-Casasnovas & Ramos, 2009).

If these socio-economic conditions change, alternative vineyard plantation and management systems are needed, and the inherited landscapes require appropriate management. Both are very important challenges for sustainable development of such regions, as well as for erosion and soil conservation research (Borselli et al., 2006; Pérez Verdú & Jofre, 2007; Martinez-Casasnovas & Ramos, 2009; see also also CERVIM and its periodical publication Mountain Vine.growing. In spite of the potential erosion risk and probably because of the control that is effectively applied, soil erosion is a systematically cited topic of concern when describing plantation and cultivation systems in these areas. A review of mean soil erosion rates for different land use types in Europe revealed that vineyards have the highest soil loss rates in the Mediterranean, i.e. 16.6 ton ha^{-1} year^{-1} (Cerdan et al. 2006). Several studies address the erosion impact caused by the implementation of new vineyard systems or as a consequence of the abandonment of formerly cultivated areas, and apply a wide range of methods for assessing erosion rates, or related land features, as shown by Rosa, 1981; Tropeano, 1983; Richter, 1991; Figueiredo & Ferreira, 1993; Martínez-Casasnovas & Sanchez-Bosch, 2000; Borselli et al., 2006.

Soil erosion is a well-known problem in Northeastern Portugal and has been systematically reported in regional soil descriptions (e. g., Martins, 1988; Agroconsultores e Coba, 1991; Figueiredo, 2001; Figueiredo, 2012). In the Douro Region (NE Portugal), where the grapes for Port Wine are produced, the problem is emphasized by its specificity and economical importance. In fact, the Douro Region was the world's first to be formally granted the statute of quality wine production region, dating back to the middle of the XVIII century, due to the originality of processes used for wine making and to the high quality of the wines produced. Since 2001, the Douro Region has become UNESCO World Heritage (Bianchi-de-Aguiar, 2000; see also UNESCO), a status that fostered socio-economic and cultural activities in the region but that highly increases responsibilities in terms of conservation and sustainable use of regional resources, as it is the case of soil and water. The Douro Region covers 250 000 ha, of which 46 000 ha are vineyards, producing several wine types including the Port, which is mainly exported (near 1 million liters annually in the last decade), with a very significant contribution to the Portuguese wine production, the wine export and the Gross Agricultural Product (Damásio et al., 2010; see also IVDP).

This Region, set along the Douro River and its tributaries, displays a strongly human-made landscape covered with vineyards cultivated on steep slopes. Heavy labour made the stabilization of these hill-slopes possible by means of traditional terracing, manually built according to models that changed through time (Bianchi-de-Aguiar, 2000). In the 1970's, in a context of growing socio-economic constraints, alternative vineyard installation and cultivation techniques were tested and progressively adopted in the 80's, namely row plantation perpendicular to the contour ("vinha ao alto") (Bianchi-de-Aguiar, 1987). Nowadays, the new system is an integral yet small part of the plantation schemes allowed under UNESCO World Heritage rules, which are understood as a recent relevant contribution to the exceptional living and active cultural landscapes that justifies the granted status(Bianchi-de-Aguiar, 2000; Damásio et al, 2010). As a high potential erosion risk system, especially considering the prevailing steep slopes, the impact of the vine row plantations in an up- down-slope direction on the stability of regional agro-ecosystems, soil and water conservation issues had to be experimentally assessed (Rosa, 1981).

It should be stressed that long-term erosion data series in Europe are quite rare (Boardman & Poesen, 2006), and they are widely recognized as highly valuable, either from the strictly statistical point of view or from that of an in-depth study of temporal variations in the occurrence and magnitude of erosion processes. This paper particularly aims at presenting the results of long-term runoff and soil loss data recorded in a set of meso-scale erosion plots installed in vineyards planted in rows perpendicular to the contour, in the Douro Region. It aims as well at identifying, and quantitatively deriving the significance, of erosion factors locally active, that help interpretations of results obtained.

2. MATERIAL AND METHODS

2.1. Study area

The study site is located in the heart of the Douro Region, near Pinhão, at Quinta de Santa Bárbara, a state experimental station (41˚10’ N, 7˚33’ W, 130 m elevation) (Fig. 1). The site represents the regional main agro-ecological features. Steep slopes dominate in the long hill-slopes draining towards the Douro River and its tributaries, the gentler slopes being found in the round crests dividing catchments of the higher order streams on schist areas. These Paleozoic schists form the largely dominant geological basement, with quartzites outcropping in narrow crests and Variscan granites in relatively wide surfaces. Soils developed under these conditions, for the most covered by shrubby Mediterranean vegetation, are shallow, with high rock fragment contents, corresponding to Leptosols, or to Regosols (rarely Cambisols) on the less steep slopes (FAO/UNESCO, 1988; Agroconsultores e Coba, 1991; Bianchi-de-Aguiar, 2000).

Fig. 1: Pinhão, the study site area in the Douro Region (UNESCO World Heritage): location and landscape, with steep slope vineyards, terraces of several types and shrubs

Besides, with strongly humanized landscapes, the Douro valley hillslopes are covered by a very large area of Anthrosols. These have a highly disturbed profile due to site preparation for vineyard plantation, associated with topographical changes caused by structural soil conservation measures, namely terraces of several types, since long applied in this Region,. Soils have a high content of fine sand and silt and a low content of clay in the fine earth; they are acid and poor in organic matter. Rock fragment content is very high, either at the surface or throughout the entire profile depth. However, organic matter contents tend to increase and rock fragment contents tend to decrease, in the surface soil layer, with time since disturbance due to vineyard installation (Agroconsultores e Coba, 1991; Bianchi-de-Aguiar, 2000; Figueiredo, 2001).

The climatic regime is Mediterranean, with rains concentrated in winter and autumn, and a typical severe soil water deficit in summer. The average annual precipitation over 30 years is 650 mm. The average maximum occurs in winter (December, 100 mm) and the minimum in summer (August, 10 mm). The mean annual air temperature is 16 ˚C and ranges from 8 ˚C in January, to 25 ˚C in July. Soil water deficit is very severe and lasts for 6 month, from mid-spring to early autumn (INMG, 1991; Agroconsultores e Coba, 1991).

Vineyards are normally planted in rows on the contour, and plantation requires deep ripper operations, that break the hard rock. Freshly outcropping rock fragments, mixed with fine earth, are further crushed by machine traffic during site preparation.

This may include also the installation of terraces, formerly with stone walls supporting a vertical raiser, nowadays with bare earthen raisers leaned at natural rest angle (Agroconsultores e Coba, 1991). Bench width depends very much on hillslope gradient but, where installed, benches are nowadays level narrow strips, less than 2.5 m wide, accommodating a single vine row, whereas in some of the older terraced areas benches were wide multiple-row strips, draining outwards (Bianchi-de-Aguiar, 2000; Queiroz et al., 2008). Alternatively, following a model spread in the Douro Region during the 80's of the XX century, some vineyards are plated in rows installed perpendicular to the contour. Changes in the plantation system with time have been pursuing economy in labour demand, increased mechanization and improved wine quality (Bianchi-de-Aguiar, 1987).

2.2. Erosion plots setup and operation

Runoff and soil loss were measured since 1978 in five plots installed in vineyards, planted in 1971, with rows perpendicular to the contour (Rosa, 1981). Plot slope gradient equals 45%, and plot area equals 1/60 ha (32.1 m long by 5.2 m width). The plots have a slightly different slope aspect. Also, plots were planted with different distances between plants and between rows, as shown in Fig. 2. The experimental design aimed at testing the effect of Treatments with different plant density, set on paired plots, except for the intermediate plant density tested on one plot only (Plot 5). The soil is a schist-derived gravely silt loam, classified as an Anthrosol (FAO/UNESCO, 1988), and, according to the analysis of soil samples taken from the surface horizon of all plots, contains on average 5 % clay, 41 % silt and 50 % fine sand, about 60 % by mass of rock fragments, and has low organic matter content (0.5 %) (Figueiredo, 2001). Estimated rock fragment cover is 55%, an average of assessments based on surface soil photograph analysis, taken in all plots as that shown in Fig. 2 (Figueiredo, 2001).

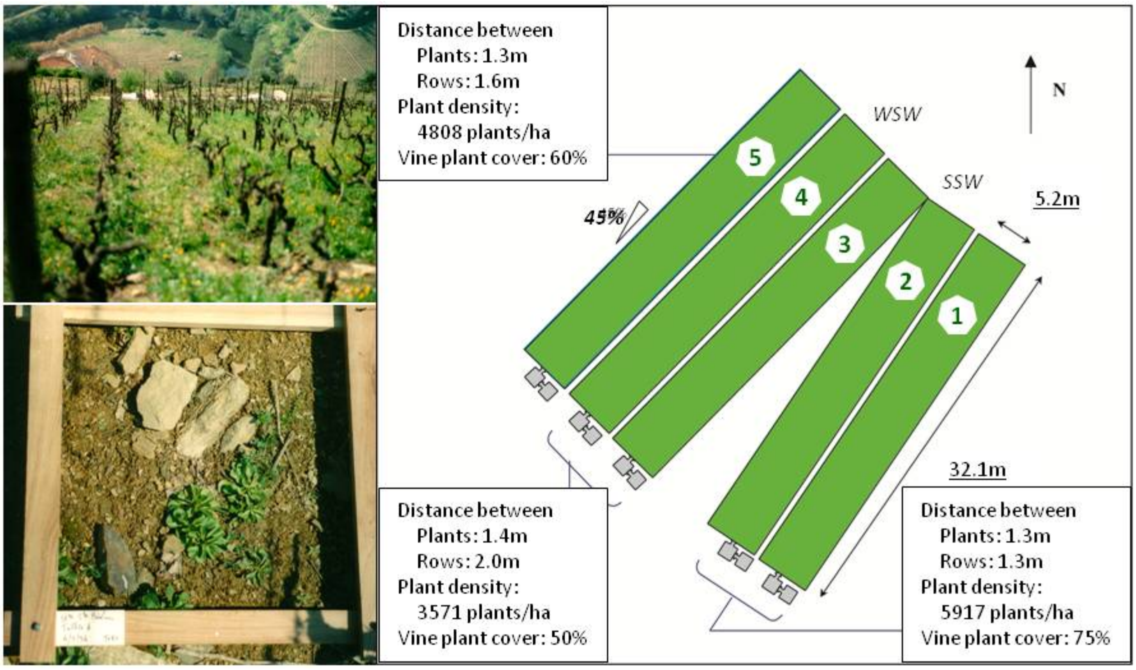

Fig. 2: Erosion plots in Douro Region vineyards at Quinta de Santa Bárbara, Pinhão: experimental setup and characteristic plot and soil cover conditions in Spring.

Runoff water and soil lost from each plot, were collected at the base of the plot, in a set of three tanks interconnected by means of 1/11 discharge slots. Each one of these allows, when the tank is full, that one eleventh of the incoming runoff passes to the next tank. During the 10-year observation period, the third tank never filled. Data were collected after each rainfall, or after several consecutive rainfall events, depending on the weather conditions, because cleaning of all tanks took about 6 h. Records of each data collection corresponded to what is hereafter named “event”. The volume of runoff water collected in each tank was measured and, after stirring, a 0.5 L sample of water plus suspended load was taken, to determine the dry sediment mass. If all sediment particles were deposited on the tank bottom, the tank was drained and the mass of the deposited sediment was determined. Runoff and sediment samples were taken about 17 times, in average, each year (Figueiredo, 2001).

A weather station provided daily data on evaporation (pan), wind speed and direction, and precipitation (pluviometer and pluviograph).

Crop management operations performed in vineyards were recorded, together with qualitative information regarding plant development. These records were matched with quantitative field assessments of ground and canopy vegetation cover (based on the analysis of soil surface photos and canopy size measurements), so as to allow deriving the annual evolution of vine canopy cover, adventitious vegetation ground cover and soil surface disturbance by tillage operations (Figueiredo, 2001).

2.3. Data treatment

Precipitation, Runoff and Soil Loss from the 5 plots, measured during a 10-year observation period (1979-1988), were analyzed at annual, seasonal and event levels. The first soil loss observations recorded dated November 19th 1978 and the last considered in the analysis dated February 14th 1989, adding up to 167 events. For the calculation of seasonal and annual values, the official dates of such periods were followed, corresponding event values were summed, and data linearly interpolated with cumulative precipitation for events covering consecutive computation periods (Figueiredo, 2001).

When assessing the overall erosional response to rainfalls produced by a soil surface under such soil and topographical conditions, a single value representing that response was computed as the average runoff and soil loss from the five plots, assuming an average vine plant cover (62%). On the other hand, individual plot runoff and soil loss values were kept when analyzing the effects of specific characteristics (i.e. vegetation cover) on their erosional response. The former approach was also possible because plots had actually a parallel response to rainfall events and the coefficients of the correlation between plot data series (either annual or event runoff and soil loss) were all statistically significant (Figueiredo, 2001).

Data extraction from the rainfall records (pluviograph bands) was the first step of precipitation data treatment. This basic data set allowed computation of rain erosivity indexes with precipitation depth, intensity for several rainfall durations, and kinetic rainfall energy, estimated according to Wischmeier & Smith (1978), adapted to SI units (Tomás, 1997). Other than the recommended truncation criteria, concerning precipitation depth or intensity, were also applied for computing rain erosivity indexes, and their performance assessed (Figueiredo, 2001). Rainfall intensity-duration-frequency curves were also derived for Quinta de Santa Bárbara, after extreme rainfall analysis (Chow, 1964).

Besides descriptive statistics computed for all data sets, correlation and regression techniques were applied as well. Furthermore, analysis of variance was applied to identify statistically significant differences in results, caused by the plot and season effects and their correspondent interactions. For multiple comparison of means the contrast method was applied (Steel & Torrie, 1980).

3. RESULTS

3.1. Runoff and soil loss rates

Annual average rainfall depth in the 10 years of records was 573 mm, with around 40 % in winter, only 7 % in summer, with spring and autumn seasons having slightly over 25 % each, as expected in a typical Mediterranean environment (Fig. 3). Global average annual runoff and soil loss were 22 mm and 361 kg ha-1, respectively, the global average runoff coefficient being 4 %. Seasonal distribution of runoff was quite similar to that of rainfall but sharply different for soil loss. Actually, spring and summer accounted for more than 80% of the annual soil loss.

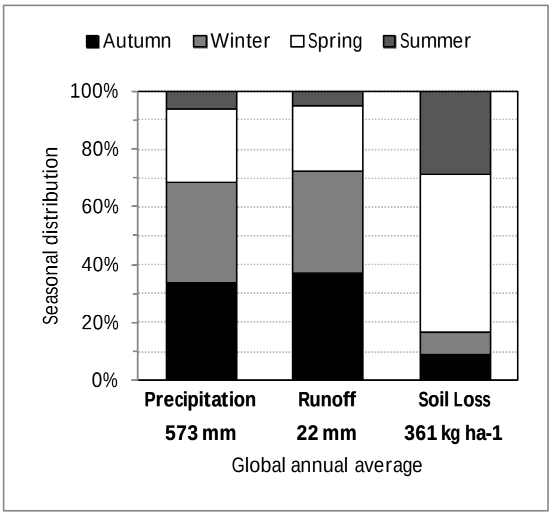

Fig. 3: Global 10-year averages of annual Precipitation, Runoff and Soil loss at Quinta de Santa Bárbara, and their seasonal distribution

Annual soil loss ranged from 50 kg ha-1 to 1906 kg ha-1, the year with the highest annual soil loss recorded contributing to 53 % of the total soil loss observed in ten years and the year with the second highest annual soil loss to 22 % (Fig. 4). Annual soil loss was in most years much lower than average (median = 122 kg ha-1) and some years (1988 and 1980) accounted for most of the soil loss recorded. Distributions of rainfall and runoff during the 10-year period were much less biased than that of soil loss. Furthermore, rankings of the three variables according to their magnitude do not match well, indicating the poor relationship between them found at annual scale (Fig. 4).

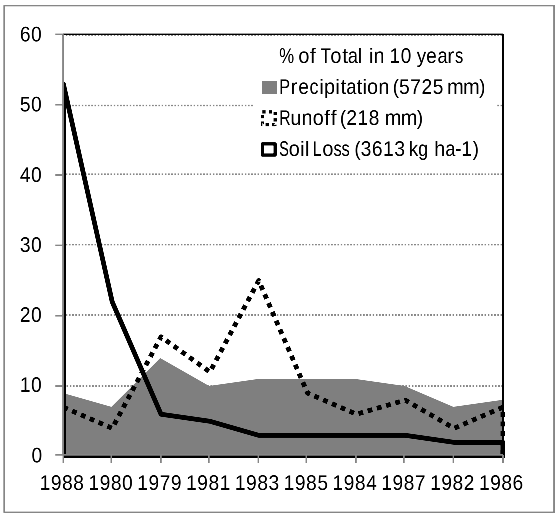

Fig. 4: Relative contribution of each year to total Precipitation, Runoff and Soil loss recorded during 10 years at Quinta de Santa Bárbara. Years are ranked from highest to lowest soil loss rates)

Annual and seasonal values presented reflect the plots' erosional response at event level. Actually, bias found in average seasonal soil loss distribution and in the annual series resulted from 4 outliers in the event data series. As depicted in Fig. 5, the event with the highest soil loss (on 27-6-1988) amounted to 833 kg ha-1 and accounted for 23 % of total erosion in ten years. The first and the second highest erosion events together accounted for 45 % of that 10-year total soil loss and occurred in two consecutive weeks (June 20 and 27, 1988). These events and the fourth event in soil loss magnitude occurred within a three-week period. The 4 events with the largest soil loss contributed for 72 % of the ten-year soil loss occurred in late spring and early summer.

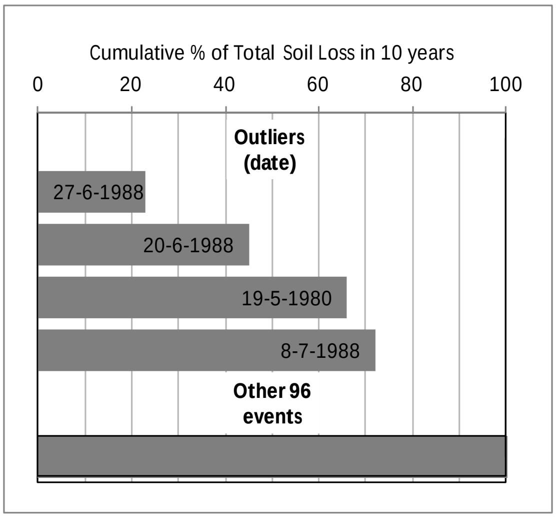

Fig. 5: Relative cumulative contribution of major erosion events to total soil loss recorded in 10 years at Quinta de Santa Bárbara. Total number of erosion events equals 100

Outliers contribute significantly to the total annual soil loss, in the case of 1980 representing virtually all the soil loss recorded (98%, Fig. 6). Annual soil loss in all the 10 years of records was, indeed, very much dependent on the contribution of the most erosive event or, of the two major events, which represented, on average, respectively 39% and 62% of the annual total soil loss. Coefficients of the correlation between annual total soil loss and that caused by the most erosive event is 0.90, increasing to 0.99 when the two most erosive events are considered.

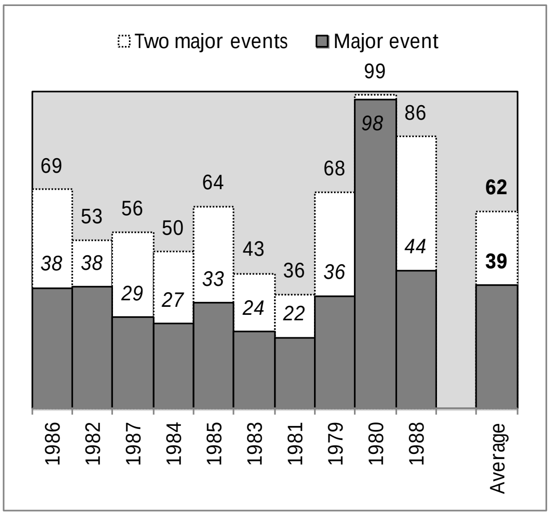

Fig. 6: Yearly and average % contribution of the largest and the 2 largest erosion events to annual soil loss (years are ranked from lowest to highest soil loss rate)

On the other hand, the 167 events analyzed include 67 producing only runoff (that may be labeled as non-erosive), while both runoff and soil loss were collected in the remainder 100 events (2/3 of the total). Therefore, a wide range of erosion conditions prevailed during the 10-year period, yielding from high-magnitude soil loss outliers to runoff events producing only clear runoff water. Consequently, the event soil loss data series shows very high dispersion around the mean value (378 % coefficient of variation, CV) and it is highly skewed (5.2 kg ha-1 median against a 7 time higher mean of 36.4 kg ha-1). The other two event data series show much lower dispersion and bias: precipitation – 128 % CV, mean 36.1 mm, 1.6 times higher than median; runoff – 255 % CV, mean 1.4 mm, 3.5 times the median.

3.2. Factors affecting plot erosional response

Rainfall erosivity is the primary factor affecting plots erosional response. From all tested rain erosivity indexes, incorporating rainfall depth, intensity and kinetic energy, in a single or combined way, the best performing one was EI30m (rainfall kinetic energy times the maximum intensity in 30 min, computed at event level, MJ ha-1 mm h-1), calculated with all rains and not with restrictions imposed in the original EI30 (Wishmeier & Smith, 1978). EI30m explains half of soil loss data variance at event level in a quasi-linear relationship (SL is event soil loss):

$$SL=0.306\ EI30m^{0.848}\ (r=0.713,\ N=100)$$

Hence, a large part of data variance is not explained by a single erosivity index or rainfall characteristic, as illustrated in Fig. 7 for the outlier events. These indeed resulted from uncommon rainfalls. However, not only differences in return period do not match differences in soil loss magnitude, but also duration for maximum return period is quite different when comparing the 4 events (the first and the fourth in magnitude were merged in Fig. 7). Other factors have to be considered for explaining recorded data.

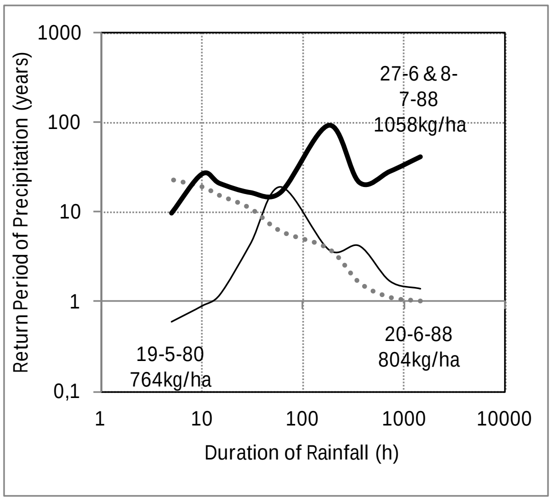

Fig. 7: Seasonal Return Period of Precipitation determining Outlier Events, as affected by rainfall duration

Average annual EI30m was 796 M ha-1 mm-1, an index very well correlated with EI30, the original version (r=0.997), but with a much poorer correlation with annual precipitation (r=0.632).

Average global estimates of vegetation cover , combining ground surface and canopy cover, reached a seasonal maximum in summer (132% of the whole-year average) and a minimum in winter (71% of the hole-year average), autumn showing a slightly higher cover than spring (106% against 91% of the whole-year average). Plots correspond to different plantation schemes and annual soil loss was significantly lower in plots with high cover (1 and 2, with 75% vines canopy cover), when compared with low or intermediate cover (plots 3 and 4, with 50% ad plot 5, with 60%) (Fig. 8). Regression analysis, applied with annual average values, show a typical negative exponential relationship between soil loss and vegetation cover (Fig. 9a). Plant density, a parameter representing vine canopy cover, relates similarly to average annual plot soil loss, yet with lower, non-significant, correlation coefficient (Fig. ??.9b). The quality of the relationships is much improved when considering median instead of mean soil loss values (Fig. 9).

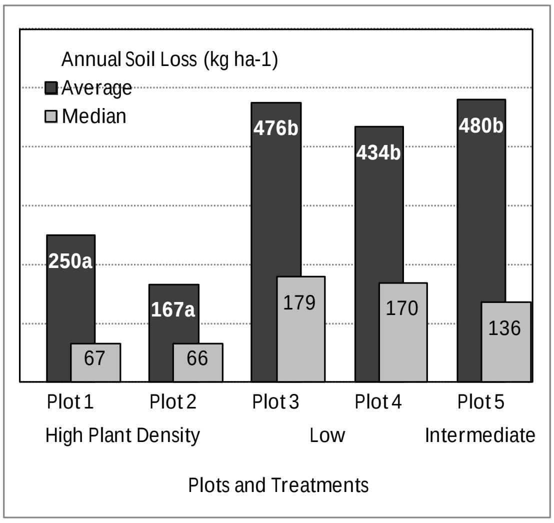

Fig. 8: Annual average and median soil loss from the erosion plots of Quinta de Santa Bárbara after 10 years of records

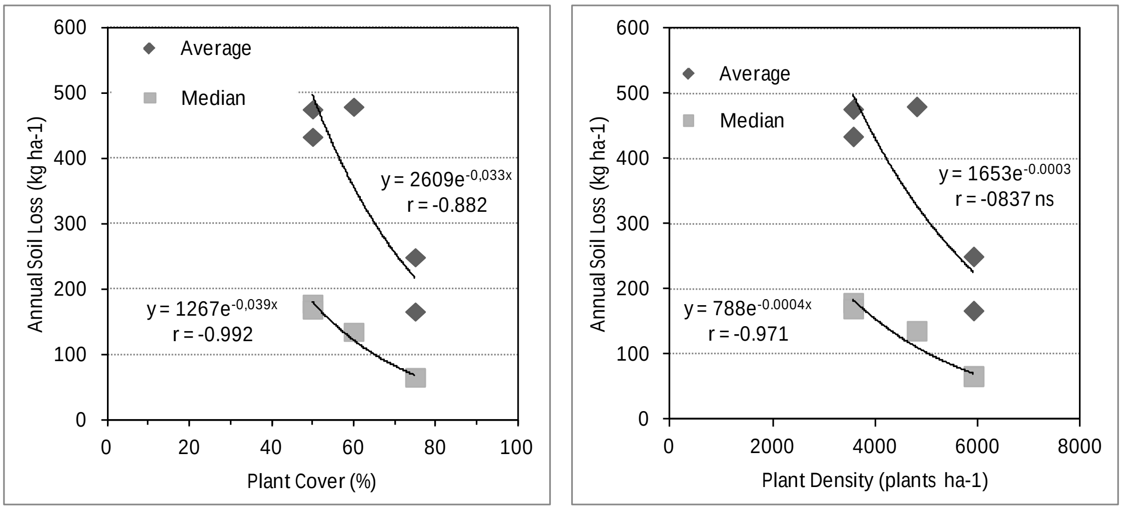

Fig. 9: Relationship between vegetation cover and soil loss mean annual values at Quinta de Santa Bárbara erosion plots: a. plant cover; b. plant density

Soil disturbance by tillage operations may result in an increased soil susceptibility to runoff erosion. The hypothesis was tested comparing event soil loss per unit erosivity index, corrected for the actual vegetation cover, prior to and after tillage operation dates recorded. These include tillage, performed in mid-autumn, and “descava”, a light operation for spring weed control. For tillage, the average change was a slight increase of +1.1 kg EI30m-1 ha-1 bare soil (with a median of 0.7), while for “descava” average and median changes were much lower (+0.1). In both cases, changes in soil loss rate were not statistically significant. For tillage, however, the range on observed changes was very large (from +42.8 to -25.1 kg EI30m-1 ha-1 bare soil).

Other factors affecting the erosional response are soil and topographical conditions prevailing in the 5 plots, which are similar in all of them (Figueiredo, 2001). Based on several studies (e. g. Hudson, 1981; Poesen 1993; Roose, 1994; Torri et al. 1997; Morgan, 2005) it can be expected that, a poorly structured, low permeability silt-loam soil, also poor in organic matter, has a very high erodibility. In addition, slope gradient is very steep in all plots (45%), thus representing a high potential erosion risk. In contrast, the very high rock fragment cover and contents of the soil in the plots effectively limits runoff erosion at the Quinta de Santa Bárbara experimental site, which is in line with results reported elsewhere (Poesen et al. 1994). Runoff and soil loss rates presented above clearly show that rock fragment cover is much more effective in controlling runoff erosion than top soil rock fragment content in promoting it in Quinta de Santa Bárbara plots.

4. DISCUSSION

Annual runoff was on average 22 mm and annual soil loss was less than 0.5 t ha-1 in all plots. Richter (1991) observed a much lower annual runoff depth, i.e. 3.8 mm year-1, for vineyards planted perpendicular to the contour in the German Mosel valley, where erosion plots were monitored on similar steep slopes and on soils having high contents of rock fragments as well but under different climatic conditions. On the contrary, average annual soil losses areis comparable to the rates reported by Richter(1991), but much lower than those measured in other wine-producing regions: i.e. 70 t ha-1 in NW Italy (Tropeano, 1983), more than 100 t ha-1 in Romania (Bianchi-de-Aguiar, 1987), 20 t ha-1 in the Ardèche Region, France (Augustinus & Nieuwenhuyse, 1986) and a mean soil loss of 16.6 t ha-1 for the Mediterranean (Cerdan et al. 2006). Under the prevailing conditions of slope gradient, vegetation cover and soil erodibility, these values highlight the strong protective effect of rock fragments (Poesen & Lavee, 1994; Poesen et al. 1994), which explains the overall behaviour of soil lost by water erosion in the Quinta de Santa Bárbara erosion plots.

Soil losses were concentrated in the spring-summer period, whereas autumn and winter showed significantly lower erosion rates in all plots. These results show a distribution of soil loss during the year which is different from that reported by most Portuguese studies on soil erosion (e. g. Ferreira et al., 1985; Coelho et al., 1990; Silva et al., 1995; Tomás, 1997), in which the main erosive season is autumn. These results reflect the effect of outlier events that occurred in late spring-early summer. They call the attention for the case of permanent crops, in which the traditional spring tillage operations may increase the soil susceptibility to erosion, in the semester when vegetation cover and precipitation characteristics were highly variable during the 10 years of records (Figueiredo, 2001), all factors that contribute to very erosive events. In fact, annual precipitation correlated well with wet semester soil loss (autumn and winter; r=0.726) and poorly with dry semester soil loss (spring and summer; r=-0.151) (Figueiredo et al., 1998), therefore indicating annual soil loss was highly dependent on the occurrence or non-occurrence of spring-summer rainstorms, while in autumn and winter smaller rain events regularly generated erosion every year. Moreover, not only short-duration low- frequency rainfalls were less intense in the wet semester when compared with the dry semester, but also the dead vine leaves protected the soil surface from direct rainfall impact (Fig. 10 and Fig. 11).

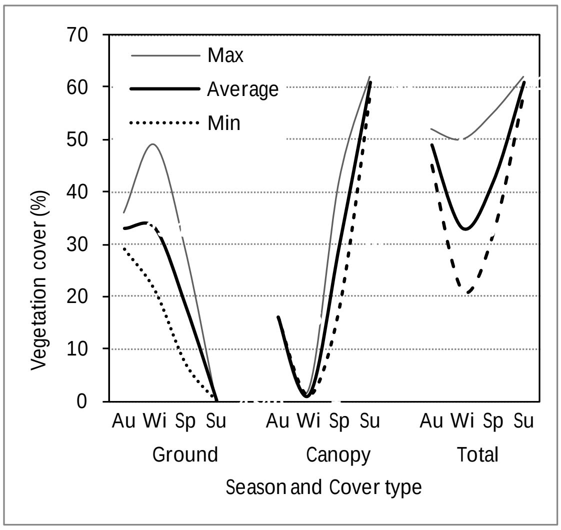

Fig. 10: Seasonal changes in mean, minimum and maximum vegetation cover at Quinta de Santa Bárbara.

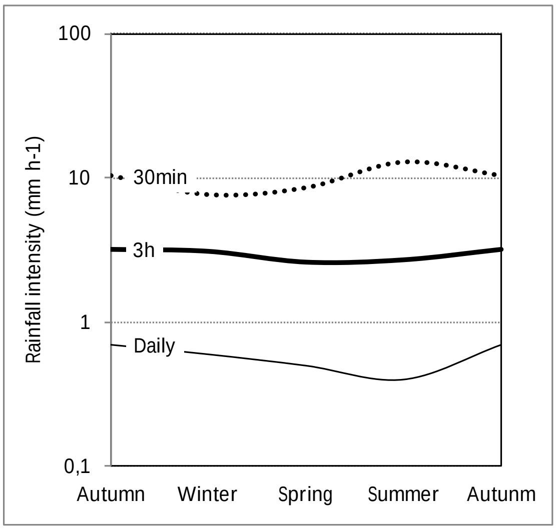

Fig. 11: Seasonal changes in average maxima rainfall intensity at Quinta de Santa Bárbara, for different rainfall duration

The four recorded outlier erosion events determined almost 75 % of the total soil loss in 10 years. This very high concentration on few events, together with the evidence of no sediment export during ca. 33 % of the total number of events, very much skewed and scattered the event soil loss data distribution. Longer term data series were treated by Tomás (1992 and 1997), regarding plots with wheat-fallow crop rotation in Vale Formoso, Alentejo, Southern Portugal. There, the most erosive year contributed to 19 to 37% of the total soil lossin 22 years and the two most erosive years accounted for 36 to 50% of that total (Tomás, 1992). Other long-term experiments (e. g. Edwards & Owens, 1991; Poesen et al., 1996; Larson et al., 1997; Shipitalo & Edwards, 1998) also show this soil loss concentration in few records (events and years); however, none of them reaches such a strong effect as that reported for the Quinta de Santa Bárbara erosion plots.

Outlier events were determined by very erosive rainfalls besides vegetation cover effects. In fact, vine canopy cover estimate was 43 % in the 1980 event, whereas in the 1988 events estimates were 71 % and 83 % in the earliest and latest event, respectively, meaning that the most erosive ones occurred when full cover was nearly reached (Figueiredo, 2001). Even though rainfall erosivity was very high (event EI30 accounting for 51 % and for 63 % of the annual values in 1980 and 1988, respectively; Figueiredo & Gonçalves, 2008), it is not possible to determine a typical rainfall duration and frequency associated to such events, as the duration corresponding to the maximum return period in each case was very different (Fig. ??.7). Moreover, no erosivity index adequately relates to the erosional response under such circumstances (Figueiredo, 2001).

As explored by Figueiredo & Gonçalves (2008), rainfall erosivity at Quinta de Santa Bárbara, in Douro, NE Portugal, was not as high as that computed by Tomás (1997) for Vale Formoso, Alentejo, SE Portugal, having the largest and longest Portuguese erosion plot data set (676 against 1038 average annual EI30, in MJ ha-1 mm h-1). In spite of the similarity in climatic regime (typically Mediterranean in both cases), Vale Formoso depicts stronger aridity (469 mm average annual precipitation) and the normally associated climatic features (e. g. rain intensity with a maximum 100 years return period and 30 min duration is 80 mm h-1, against 66 in Quinta de Santa Bárbara) (Figueiredo & Gonçalves, 2008).

As stated above, with the soil and topographical conditions prevailing at Quinta de Santa Bárbara, and considering that vine rows do not provide full cover of the soil surface, soil loss rates recorded are actually very low. This is explained by the effects of the very high rock fragment content and cover in significantly reducing soil erosion rates on such hill-slopes. Figueiredo (2001) developed an explanation for the low soil loss rates observed related to rock fragment cover. As rock fragments affect sediment transfer along the hillslope, due to their effects on surface roughness and overland flow tortuosity, their effects actually also interact with the effects of slope length on soil loss (Figueiredo et al., in prep.). This slope length effect adds to the effect of cover, which directly controls fine earth particle detachment due to raindrop impact (Figueiredo et al., 2004).

5. CONCLUSIONS

Results discussed above lead to the following conclusions:

a) Average annual soil loss, from the five erosion plots reported in this study, was below 0.5 t ha-1, which is very low compared to soil loss rates normally reported for Mediterranean vineyards;

b) The very high rock fragment contents and cover of the soil is the single mitigating factor that helps explaining the observed low erosion rates;

c) Plantation scheme, affecting plant density and vegetation cover, significantly contributed to explain differences in observed soil loss between plots;

d) Runoff erosion was concentrated in the spring-summer semester, when more than 75 % of average annual soil loss occurred, mainly due to high-magnitude erosion events that occurred in those seasons following low frequency rainfalls, and they contributed to almost 75 % of the total soil loss recorded in 10 years.

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