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Effects of wind driven rainfalls on soil loss from a Douro vineyard, Portugal

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Abstract

In permanent row crops, rainfall interception by canopies in rows varies according to wind direction and this may affect raindrop impact and erosion in the inter-row area. The paper aims at discussing the effects of wind direction during rainfalls on soil loss from vineyard plots with different slope aspect in the Douro Region, Portugal. Long term continuous rainfall records, daily wind direction, and soil loss from 5 plots (32m long x 5n wide), in a 45% slope row-planted vineyard, with slope aspect from NW to SW, were explored separating events only with water loss (NER, 67 non-erosive events) from the others (ERO, 100 erosive events), and considering for each event wind direction at peak rainfall intensity. Calm atmosphere prevailed but with lower frequency in ERO (65%) than in NER (72%). Most frequent winds were NW (20%) and S (11%) in ERRO, and SE (12%) and NW (7%) in NER. Wind direction affected the differences between plots in event soil loss (expressed by the CV of the 5 plots soil loss in each event), with a CV 90% for NW winds, 37% for S, and 33% for Calm. NW winds blow parallel to vine rows in some plots and almost perpendicular in the others and this effect was most evident during the larger erosion events, when lowest to highest plot soil loss ratio reached 1:50. These results may contribute to better tune the application of conservation measures in Douro vineyards considering plot location and dominant wind direction.

Keywords: Wind-driven rainfalls, wind direction, rainfall erosivity, soil erosion, vineyards, Douro Region.

Introduction

Rainfall erosivity is related to both kinetic energy of raindrops and rainfall intensity (Morgan, 2005). Kinetic energy of raindrops hitting the ground converts to disruptive work of surface soil aggregates, determining compression of the uppermost soil, detachment of soil particles and their redistribution over the surface, both generating a sealed layer (Assouline, 2004; Armenise et al., 2018). The balance between rainfall intensity and soil infiltration rate generates excess precipitation at surface, which evolves to runoff, faster as the surface is smoothened by the sealing process (Salles et al., 2000). The loose detached particles become readily prone to runoff wash (Beuselinck et al, 2002). As so, the most common erosivity index (EI30, or the erosive storm kinetic energy times its máximum intensity in 30 min) precisely accounts for both rainfall characteristics (Wischmeier & Smith, 1978).

Erosivity indexes and most erosivity studies assume vertical rain under calm atmosphere. However, lab experiments addressed the effect of wind driven rainfalls on their erosive power and on their effects on overland flow velocity. In one hand, wind forces increase raindrop kinetic energy, leading to a higher potential soil detachment, with consequences for sealing and wash potential (Marzen et al, 2015). On the other hand, wind driven rainfalls increase friction losses on running water over the soil surface (de Lima, 1989), meaning a reduction in flow velocity and soil particles wash. In spite of the recent advances in the study of erosion processes under wind driven rainfalls (Marzen, 2017), there is no actual procedure to reliably account for the effect of wind driven rainfalls in erosivity estimates.

Under field conditions, it is generally assumed that rains fall uniformly over a continuous soil cover by crops, the first interception layer corresponding to canopies or the above ground vegetation, the second one corresponding to surface soil cover by weeds or residues. This is clearly an inadequate approach in the case of permanent crops. Some are aligned in plant rows, as it is the case of vineyards, therefore shaping a discontinuous, yet regular, vegetation cover structure.

In permanent row crops, rainfall interception by canopies varies according to wind direction and this may affect raindrop impact and erosion in the inter-row area (Figure 1a). In this case, rainfall erosivity and the erosional response of row planted plots to rainfalls depends on wind direction, besides the eventual effect of wind speed. For storms occurring on a farmed area, plot erosive response may be quite different according to direction of the wind driven drops as compared to the direction of plant rows (Figueiredo, 2001). These may shadow more or less effectively the inter-row area from raindrop impact. Literature lacks information about this effect, which may help explaining inconsistencies in experimental erosion studies and may help tuning soil conservation strategies in vine-growing regions. It should be noted that wine yards are among the most critical cropping systems in Europe, in what concerns actual erosion rates (Cerdan et al, 2008). Soil conservation is part of the traditional planning and management in Douro Region viticulture but such care with the soil resource should be kept in actual viticulture development, especially considering the extent of high potential erosion risk vine-growing areas, set on very steep slopes and over highly erodible schist derived soils (Figueiredo, 2015).

The paper aims at providing a preliminary discussion on the effects of wind direction during rainfalls on soil loss from vineyard plots with different slope aspect in the Douro Region, Portugal.

Materials and Methods

Long term data records from Quinta de Santa Bárbara state experimental station were explored by Figueiredo (2001) and further in this study. It is located in the Douro Region, Portugal (41˚10'N, 7˚33'W and 130m elevation), in the heart of the Port Wine producing area, qualified as UNESCO World Heritage (Bianchi-de-Aguiar, 2002). Records comprised a 10-year series of continuous rainfall data (pluviograph), daily wind speed and direction, and soil loss from 5 plots (32.1m long by 5.2m wide), installed in a 45% slope vineyard, planted in rows against the contour, with slope aspect varying from WNW to WSW (Figueiredo et al, 2013; Figueiredo, 2015) (Figure 1b).

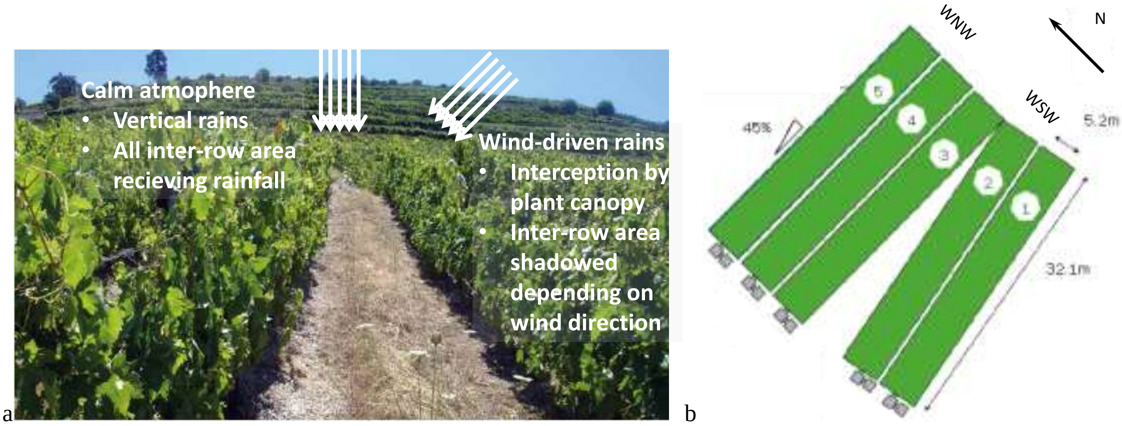

Figure 1 – A Douro vineyard in early summer , planted in rows against the contour, with a schematic representation of vertical and wind-driven rains, and the effect of vine rows interception (a), and a sketch of Quinta de Santa Bárbara erosion plots (with different slope aspect), located in the Douro Wine Region, Portugal (b).

A total of 167 data collections in the 5 plots were recorded, with an average of about 17 records of runoff water and soil loss per year during 10 years. Each record corresponds to a precipitation period, named hereafter event, for which rainfall characteristics such as height, intensity, kinetic energy, erosivity indexes, were determined in detail (Figueiredo, 2001). For each event, wind direction at peak rainfall intensity was identified matching rainfall and wind direction series. Winds with no direction assigned, corresponding to calm atmospheric conditions (< 2 km/h), were screened from the wind speed data series.

In 67 events, only runoff water loss was recorded and they were named non-erosive events (NER), while the remainder 100 events, named erosive (ERO), yield water and soil loss. Data analysis focused on the comparison of these two types of events as they represent different plot erosional responses to rainfalls, whereby NER had much less impacto soil resource tan ERO.

Results and Discussion

Calm atmosphere prevailed in most of the runoff and soil loss events, with 105 out of 167 (Figure 2a). Comparing plots erosional response under calm and windy conditions, Figure 2a shows a much larger proportion of erosive events on windy than on calm conditions (69% against 54% of each group of events), meaning more soil loss is associated to wind-driven than to vertical rains. In fact, 70% of the total soil loss recorded in the 5 plots in 10 years occurred in windy events.

Wind direction frequency distribution of windy events is different in NER as compared to ERO events (Figure 2b). In these, NW direction is dominant (20%), followed by the S winds (11%), while in NER, SE winds were dominant (12%) followed by the NW winds (7%). Figure 2b also stresses the larger share of calm conditions on NER events.

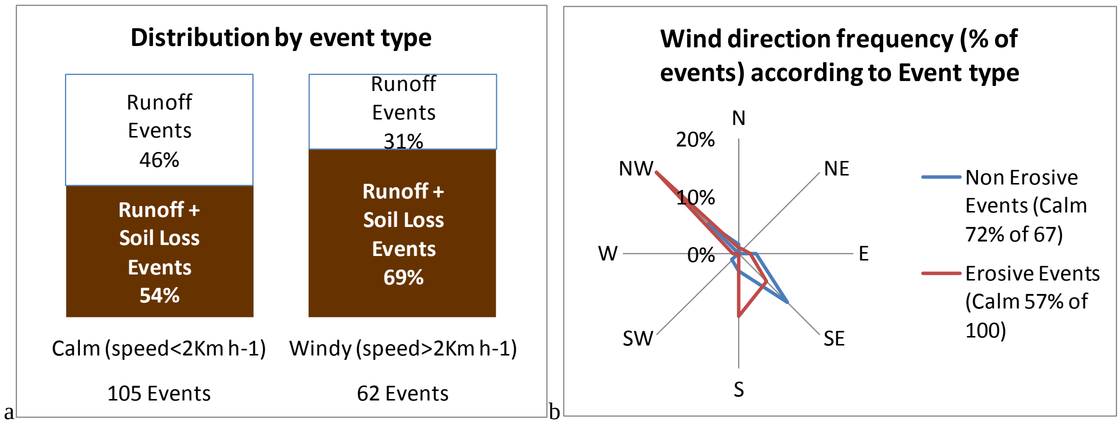

Figure 2 – Frequency distribution of event types for Calm and Windy conditions (a), and Wind direction frequency distribution for the two event types, Erosive and Non-Erosive (b).

However, windy conditions affected differently the erosional response of each one of the 5 plots (Figure 3). From plots 1 to 5, average soil loss was progressively higher in windy events as compared to those occurring in calm conditions. On plot 1 windy events average soil loss was one fifth of that of calm events, while in plots 2, 3, 4 and 5 it was about one third, half, the same and 1.5 times higher, respectively. Furthermore, soil loss in wind-driven rainfall events with certain wind directions (W, NW and E) soil loss was much higher than in others (S, SE, N and NE) (Figure 4).

The hill-slope where plots were installed changes in slope aspect and so plots face different directions. According to the work hypothesis set for this study, under these circumstances, wind-driven rainfalls with similar direction could affect differently plots erosional response. This is also confirmed in Figure 4.

The differences between plots in response to rainfall under calm conditions is expressed by a CV of the 5 plots average event soil loss of 33%. In windy events, the CV were higher than this for wind directions, ranging from 37% to 90%. Very high CV were computed for NW (90%) and W (80%), where average soil loss was higher, meaning that for such wind directions plots erosional response showed the most important differences. The same occurred also in NE direction (CV = 82%) but in this case average soil loss was generally very low.

NW winds are associated to high average event soil loss and very large differences in plot response to wind-driven rainfalls. These winds blow parallel to vine rows in some plots and almost perpendicular in

the others. In the first case, the less protected area between vine rows freely impacted by raindrops generating an erosional response that can be described considering the erosion factors action (rainfall and soil cover), formulated in common terms. In the second case, vine rows act as interception screens and the less protected inter-row area may receive limited rainfall amounts directly impacting the soil surface. In such cases, plots with different slope aspect may show sharply different erosional responses. It should be noted, however, that differences between NW and SE average event soil loss apparently reflect that rainfalls acting up-slope (SE) have a much lower effect on soil loss than those acting down-slope (NW).

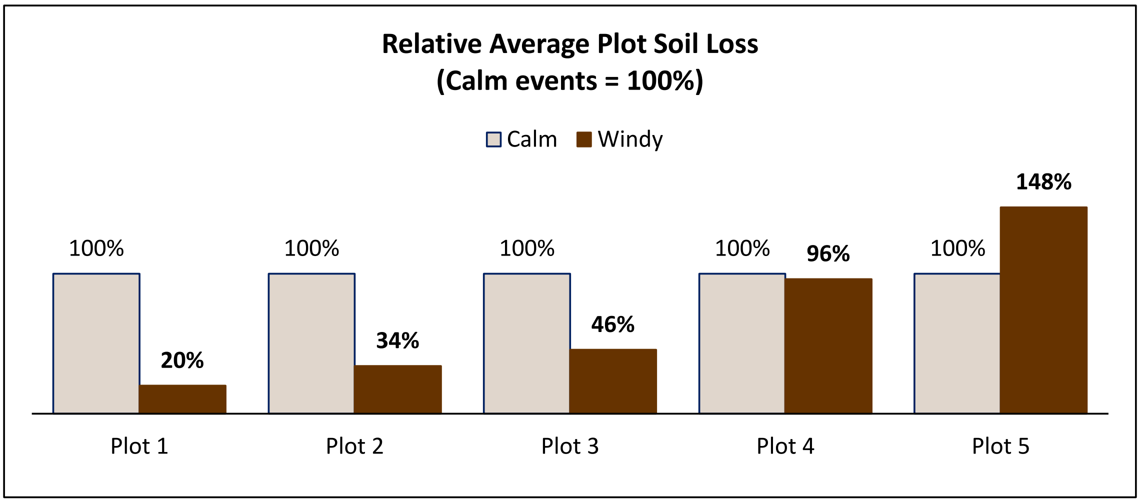

Figure 3 – Average plot Soil Loss in Calm and in Windy events, expressed as a percentage of the Calm events average.

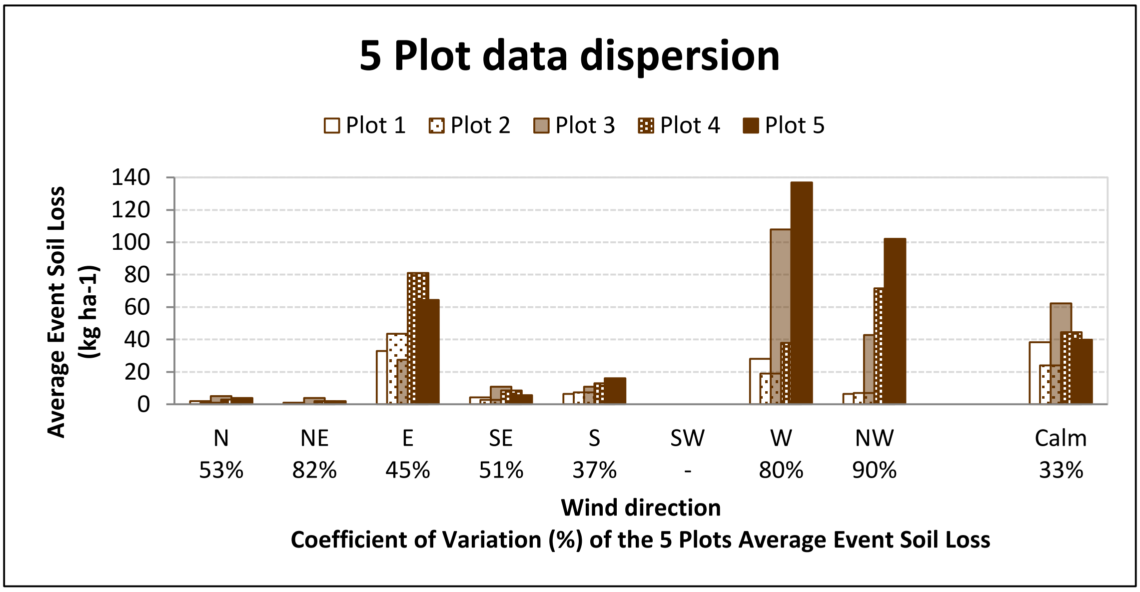

Figure 4 – Event soil loss in the 5 plots for each wind direction and calm events: plot averages and its dispersion, assessed by the coefficient of variation (CV) of the 5 plot averages.

From the 100 erosive events recorded in Quinta de Santa Bárbara erosion plots, 4 were considered extreme events or outliers in the soil loss data series (Figueiredo et al, 1998; Figueiredo et al., 2013). They contributed to 75% of the total soil loss recorded in 10 years. Wind direction on these events was only assigned in one case (NW), the third in event soil loss rank that accounted for 20% of the total soil loss in 10 years. In such large erosion events the above described effect of vine rows direction as related to wind direction during rainfalls was most evident. In fact, in this event the ratio between the lowest (plot 2) and the highest (plot 5) soil loss reached 1:50 (Figueiredo, 2001).

Conclusion

This study was an exploratory work on a topic that is very scarcely addressed to in soil erosion literature. The topic is especially relevant for permanent row crops in sloping areas, as it is the case of the Douro Region vineyards, where a high potential erosion risk prevails.

The analysis of long term data from Quinta de Santa Bárbara erosion plots, set in the vineyards of the Douro Region, Portugal, clearly showed that wind direction during erosive rainfalls affects plots erosional response. Moreover, as plots have different slope aspect, vine rows direction varies accordingly. The same wind direction during a rainfall may yield very different event soil loss when comparing plots where the vine rows impose an interception screen to raindrops (wind perpendicular to vine rows), with those where the inter-row área is freely impact by rainfall (wind parallel to vine rows). This effect was even more evident in very large erosion events.

As the plantation scheme determines the vineyard vegetation cover structure, these results may contribute to better tune the application of conservation measures in Douro viticulture, considering plot location and dominant wind direction. They also contribute for a better interpretation of experimental data on soil erosion in sloping vineyards.

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