

## Consiglio Nazionale delle Ricerche Short Term Mobility 2016

Scientific Report

### Implementation of RUSLE in Mediterranean vineyards

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#### Introduction

Soil erosion by water has been identified as one of the major threats that affect European agricultural soils. Olive groves and vineyards are often situated on steep hill slopes in areas where the annual rainfall is low but subject to high intensity rainstorms. Measured data showed that in the Mediterranean region the highest runoff rates are related to tree crops and vineyard land use. Some of the highest rates of soil erosion in the Mediterranean region have been found in olive groves and vineyards on sloping land, where soil is tilled to maintain a bare soil surface to save water for the crops (Cerdan et al., 2010).

Analysis with simulation models is a way to evaluate the impact of changes in soil management on soil erosion risk under contrasting situations, and the Revised Universal Soil Loss Equation (RUSLE) remains as the most widely used. Despite its relative simplicity, a proper calibration for a given situation can be challenging, especially in situations outside of those widely covered in the USA.

To overcome this problem some authors have proposed simplified procedures, such as the summary model proposed by Gómez et al. (2003) for use of RUSLE in olives, the determination of USLE C factors from cumulative field measurement soil erosion in vineyards (e.g. Novara et al., 2011) or calibration of the parameters required to determine the USLE C factor (Auerswald and Schwab, 1999).

However, the values derived following these approach are sometimes difficult to extrapolate outside the conditions for which they were developed. Additionally, due to the further development of RUSLE, currently in its version 2 (Dabney et al., 2012) some of these simplifications are far from the assumptions presently used by RUSLE (Dabney et al., 2012).

The main objective of the collaboration between IMAMOTER and IAS is the implementation of the RUSLE model in vineyards to evaluate the effect of soil management on soil erosion risk under different scenarios. A proper calibration of the RUSLE2.0 version of the model was carried out by means of an approach similar to the one proposed by Gómez et al.(2003) adapted to the specific situation of vineyard management, and afterwards RUSLE will be applied to predict soil losses in the long term in vineyards located in Southern Spain and North Italy.

This reports presents the preliminary results of the calibration of a simplified EXCEL tool for implementing the RUSLE 2 model in vineyards for stakeholders with limited datasets (Gómez et al., 2016), in order to evaluate the runoff and soil erosion in sloping vineyards in relation to different soil managements. Validation and calibration of the model was made by means of the Cannona Data Base (CDB) (Biddoccu et al., 2016). It includes long-term soil and climate dataset (measurements of rainfall, runoff, sediment and soil physical characteristics, and climate parameters), which were collected by IMAMOTER from the Cannona Erosion Plots since 2000. After calibration, RUSLE could be applied in order to evaluate the effect of soil management on



the runoff and soil erosion in sloping vineyards, in relation with different conservation measures and future climate scenarios.

#### Methodology

#### The RUSLE2 model

The Revised Universal Soil Loss Equation, Version 2 (RUSLE2), is the most recent in the family of Universal Soil Loss Equation (USLE)/RUSLE/RUSLE2 models proven to provide robust estimates of average annual sheet and rill erosion for one dimensional hillslope representations.

Those models are based on the following equation, that estimates average annual erosion using rainfall, soil, topographic, and management data:

where A: annual average soil loss (t  $ha^{-1} yr^{-1}$ ), R: rainfall erosivity factor (MJ mm  $ha^{-1}h^{-1}yr^{-1}$ ), K: soil erodibility factor (t ha h  $ha^{-1}MJ^{-1}mm^{-1}$ ), C: cover-management factor (dimensionless), LS: slope length and slope steepness factor (dimensionless), and P: support practices factor (dimensionless).

The cover-management factor C is the most complex factor, describing the effect of vegetation (e.g. cover, biomass) and soil physical characteristics (e.g. consolidation, roughness) on soil detachment. The C factor is the product of subfactors, as:

$$C = c_c g_c s_r r_h s_b s_c s_m$$

where:  $c_c$  = canopy cover subfactor;  $g_c$  = ground cover subfactor;  $s_r$  = soil roughness subfacor;  $r_h$  = ridge subfactor;  $s_b$  = soil biomass subfactor;  $s_c$  = soil consolidation subfactor;  $s_m$  = soil moisture subfactor.



Fig. 1 – Summary of the EXCEL tool structure.

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The equation was obtained on the basis of experimental data obtained from erosion plots throughout the USA. Even with its relative simplicity compared to other, more process based, erosion model, the RUSLE2 model requires proper calibration, especially in situations outside of those widely covered in the USA, where it was developed.

An EXCEL tool was built to allow the calibration of RUSLE2 by assuming the simplified situation of an homogeneous hillslope. The structure of the tool is shown in Figure 1. Each of the factors of RUSLE is calculated in one, e.g. R, or more, e.g. C, sheets of the Excel tool. Each factor is accompanied by a set of explanations and accompanying information, Figure 2.

The assumption is that with basic information on daily rainfall and temperature, crop evolution, canopy and ground cover, tillage and topography it is possible to calibrate RUSLE2 taking into account the interactions among different factors and subfactors in a relatively easy way. This can facilitate understanding the erosion risk of different management by stakeholders, or other applications such as comparison of erosion risk among different management , soil, temperature and rainfall regimes. For more complex situations, e.g. complex slope profiles, the user should calibrate the RUSLE2 software.



Fig. 2 – Example of model screen.

#### Available input data

Long-term runoff and soil erosion data have been collected for more than 15 years from differently managed field-scale vineyard plots within the "Tenuta Cannona" Experimental Vine and Wine Centre of Agrion (before Regione Piemonte), which is located in the "Alto Monferrato" vine-growing region (Piedmont, NW Italy), at an average elevation of 290 m asl. The climate is temperate, with a mean annual air temperature of 13°C and an average annual precipitation of

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875 mm (calculated in the 2000-2011 period). The three experimental vineyard plots are adjacent to each other on a hillslope with SE aspect and average slope of 15%. Soil is classified as *typic Ustorthents, fine-loamy, mixed, calcareous, mesic* (Soil Survey Staff, 2010). Each plot is 1221 m<sup>2</sup> (74 m long and 16,5 m wide), with rows aligned along the slope. During the period of observation, a different cultivation technique was adopted on the soil between the vine rows of each plot: conventional tillage (CT), which was carried out with a chisel at a depth of about 0.25 m; reduced tillage (RT), with a rotary cultivator to a depth of 0.15 m; controlled grass cover (GC), with spontaneous grass controlled by mowing during the year. Tillage and mowing were usually carried out twice a year, in spring and autumn, or in spring and summer. Under the vine-rows of all the three plots, grass was controlled by chemical weeding in spring.



Fig.3 – The Cannona Erosion Plots

Since 2000 rainfall and runoff gauges have collected data for each rainfall-runoff event. Sediment concentrations in collected water have been monitored to permit evaluation of the soil losses. During the period of observation surveys have been carried out to investigate spatial and temporal variability of the soil bulk density, soil moisture, penetration resistance. The Cannona Data Base (CDB) includes data for more than 200 runoff events and over 70 soil loss events; moreover, periodic measurements for soil physical characteristics are included for the three plots. The monitoring methods used at the Cannona Erosion Plots and the Database are described in Biddoccu et al. (2016). In addition to data of the CDB, soil properties were obtained from the soil map of Regione Piemonte (Regione Piemonte, 2012) and from the atlas of soil of Piedmont (IPLA, 2009).

Additional values for BD and hydraulic conductivity of the topsoil were obtained from field measurements carried out by Biddoccu et al. (2017). Data about percentage of ground cover by grass were obtained from a series of surveys conducted in 2013 (Repullo et al., 2013). Information about the vine growth, dates representative of vine growth in the area and soil operation were obtained from the reports compiled by the staff of the "Tenuta Cannona" Centre. Further climate data are available for neighbouring climate stations from the ARPA Meteorological DataBase (ARPA Piemonte, 2013).

The CDB offers the possibility to evaluate the seasonal and annual variability of the hydrological and soil erosion processes with the adoption of water/soil conservation measurements, as grass cover maintenance. The dataset is suitable for a proper calibration and validation and calibration of the RUSLE2 model.



### Input Data

Data available for the Tenuta Cannona Erosion Plots were collected and used to compile the RUSLE2 Excel Tool input sheets:

- 1. Rainfall erosivity
- 2. Soil erodibility
- 3. Canopy and ground cover
- 4. Slope length and steepness
- 5. Cover and management subfactors (multiple sheets): soil consolidation, canopy cover, soil roughness, soil biomass, ground cover, ridge subfactor, soil moisture

For most of the factors (or subfactors) a separate sheet provides explanations and information useful to fill the input sheet.

### 1. Climate file

The RUSLE2 Excel Tool requires cumulative distribution of rainfall erosivity by quarters, which can obtained means of RIST Rainfall Intensity Summarization Tool be by -(http://www.ars.usda.gov/Research/docs.htm?docid=3251) using hourly or sub-hourly precipitation data. Hourly data of the Cannona climate station and 10-min data from the Ovada station (ARPA Meteorological Data Base, courtesy of Arpa Piemonte) were used to obtain the rainfall erosivity for each storm and rainfall erosivity distribution by quarter for years from 2000 to 2014.

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Fig.4 – Rainfall erosivity data sheet and graph showing its distribution by quarter.

2. Soil erodibility

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The RUSLE2 Excel Tool requires information about soil texture, organic matter content, soil structure class, soil profile permeability, that is used to calculate the baseline K-factor. The input sheet gives also the option to calculate a variable K-factor for each quarter, based on empirical adjustment from daily average temperature and precipitation. If this option is selected, daily climate data must be inserted in the sheet.

For the Cannona Erosion Plots, texture and organic matter content were obtained from soil samples that were taken in December, 2014. Soil permeability class was estimated, based on infiltration tests carried out in different dates along a 2-years period (between October, 2012 and November, 2014) (Biddoccu et al., 2017). Daily air temperature and rainfall measured by the Cannona weather station were included in the sheet for each year.

#### 3. Canopy and ground cover

Soil cover by standing vegetation and by residues and other inert materials such as rock are some of the key elements in soil management aimed to reduces soil erosion. Such information are used in the determination of subfactors of the c factor: canopy cover (cc) and ground cover (gc). They are also used when the option of calculating the m exponent of the slope length factor (L) is chosen.

In this sheet the user has to introduce the best estimation of variables used to determine ground cover by vegetation (ground cover of the tree and of the cover crop) and residues (vegetation residues and rock fragments) for each quarter. They can be derived from measurements, published studies or using different modelling approaches, such as for instance WABOL (Abazi et al., 2012), for the evolution of the cover crop. Data about percentage of ground cover by grass in the Cannona Erosion Plots (CT and GC) were obtained from surveys conducted in 2013 (Repullo et al., 2013). The ground cover by vines, vegetation residues and rock fragments was estimated from field observations. Canopy and ground cover information was adjusted year by year, based on timing when operations on vines (e.g. pruning, harvest) or grass (e.g. mulching or herbicide spraying under the vine rows) were carried out by the farmers.

#### 4. <u>Slope length and steepness</u>

The RUSLE2 summary model can only simulate an homogeneous slope without a complex profile. A major change compared to previous USLE and RUSLE versions is that the expression for the m factor changes in RUSLE2. This factor can be updated in time in relation to the evolution of ground cover and it is calculated also introducing the relationship between rill and interill erodibility (kr/ki). This summary model gives the option to calculate this variable m factor, or to introduce a constant m factor according to the evaluation of the dominance of rill or interrill erosion.

Each one of the Cannona Erosion Plots can be approximated quite well by an homogeneous slope, which length is 75 m and slope steepness of 15%. The option of variable *m* factor calculation was used for all the tests.



#### 5. Cover and management factor

As above mentioned, cover and management factor (C-factor) depends on several subfactors (Fig.5) described below. They are updated every quarter depending on the evolution of variables defining them.



Fig.5 – Example of the variability during the year of the C-factor and its subfactors in the CT plot.

a) sc: Soil consolidation subfactor. It depends on the time since last soil disturbance. It is used for situations where no mechanical disturbance of the soil surface happens in the long term. For instance a permanent cover crop controlled by mowing (as the GC plot in Cannona) or herbicide, or a bare soil maintained with herbicide and no plowing.

It depends on two variables. One is time since last disturbance, td, and the other is time to consolidation, tc. tc is estimated according to the RUSLE2 estimations of a longer tc for dry areas (20 years for rain lower than 250 mm/year) and shorter in rainy areas (7 years for rainfall higher than 760 mm/year). It is interpolated between those two situations.

The subfactor was constant (equal to 1) in case of some mechanical disturbance occurs during the year. Otherwise (as in GC in Cannona), data requested are (i) time (years) since last mechanical disturbance, (ii) the average annual rainfall (mm) in the area, (ii) time to consolidation (years) in the area (7 years) for the Cannona plots.

b) cc: Canopy subfactor. It depends on the cover by vegetation above the ground.

In this sheet some representative input values are requested for proper determination. They are related to the tree canopy (maximum soil coverage, representative height of fall of drops, height from the soil to bottom and to top of the canopy, coefficient of the canopy shape) and similarly for the cover crop. The requested data were estimated from field observations.

c) sr: Surface roughness subfactor. It depends on the surface random roughness

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Soil roughness is one of the key parameters in determing the C factor. It can be highly variable and requires as input daily rainfall depth and rainfall erosivity. Furthermore, if some kind of tillage operation is performed during the year (up to 10 operations in a year), it must be defined in according to the RUSLE2 database and its execution is indicated in the occurrence day. All data are used to allow intermediate calculation and daily updating of the subfactor.

For the Cannona Erosion Plots tillage operations were defined for the CT plot and considered in the corresponding time, in according to the farmer recordings.

If significant tillage is not performed (e.g. using herbicide and or letting a ground cover to develop), a long-term roughness value can be used, including the effect of biomass and time to consolidation. As a simplification it assumes a constant value for the whole year.

d) sb: Soil biomass subfactor. It depends on the biomass (of residues and roots) into the ground.

This parameter considers the effect on erodibility due to the presence of residues and root biomass within the top 25 cm of the soil. The user has to fill the information required to approximate the amount of root (live and dead) and residue averaged over the top 25 cm of the soil. In case the user has not available data, he can use values from other studies in the region or from the RUSLE2 database. The appropriate values for the Cannona plots were chosen from the RUSLE2 database.

e) gc: ground cover subfactor. It depends on surface ground cover by rocks and residues.

This parameter considers the effect on erodibility due to the presence of residues over the soil surface already in contact with it. Its determination uses information, already included, on soil textural clasees (in K factor), in soil root and biomass content (in sb subfactor), and in slope steepness (in S factor).

The user has to fill the information required to approximate the amount of residues over the ground in the sheet "Canopy and ground cover" and to indicate the factor defining conformance of average residue to the soil surface.

### f) rh: Ridge subfactor. It depends on the ridges formed by tillage.

This parameter considers the effect on erodibility due to flow concentration occurring when there are well formed ridges oriented in up-down slope. It is higher for taller ridges and up-down oriented ridges, and negligible when ridges are on-contour. Do not confuse with the contour tillage which is included in the support (P) factor. A variable ridge height can be considered only if a variable Ra has been considered before in the "soil roughness" subfactor determination.

g) sm: Soil moisture subfactor. Depends on the moisture of the topsoil layers (0-30,0-40 cm).

Soil moisture subfactor is introduced to consider properly the effect on soil erosion of the drying and wetting of the soil. RUSLE2 considers this factor only for a very specific area of the NW USA. It

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can be used as an alternative to the temporal adjustment of K if it presents a poor performance. For tree crops, such olives, the temporal variation of erosion due to changes in soil moisture have been modelled with good results using a soil moisture, SM, subfactor, instead of the empirical calibration with T<sup>a</sup> and rainfall incorporated in the K factor. Note that if you choose the use of a *sm* subfactor you should use an constant K value for the whole year. The *sm* factor is 1 when the soil profile is at field capacity and 0 when it is at permanent wilting point.

The model determines an approximation of the water balance of the top soil using the single crop coefficient approach and assuming the calculation of Eto using the Hargreaves equation. It is a compromise between data requirement and accuracy. It provides the user a realistic evolution of the soil moisture in the plot.

Data requested are: soil depth for water balance (600 mm as default), average soil field capacity, soil average permanent wilting point, average annual runoff coefficient, average soil moisture on January first. Then quarter data or estimation of solar radiation and Kc values (for tree crop) are requested as described in the info sheet.

Data for the Cannona plots were estimated in according to the instructions or obtained from direct measurements.

#### Calibration STRATEGY

Available data for the Cannona Erosion Plots were collected and processed to complete the factors and subfactors sheets for the CT and GC plots in the considered years.

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Fig.5 – Example of the output of the RUSLE2 Excel Tool.

Then different runs of the model were considered and the performance of the model was evaluated in order to calibrate it. The "options" considered in the different runs were:

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- 1) variable K and constant *sm* factor, using rainfall erosivity from Ovada 10-min data
- 2) constant K and variable *sm* factor, using rainfall erosivity from Ovada 10-min data
- 3) constant K and variable *sm* factor, using rainfall erosivity from Cannona hourly data

The output of the RUSLE2 Excel Tool is resumed in the "General" sheet (Fig. 6), where quarter values for all factors are reported, along with the corresponding estimated soil losses. An annual summary is also provided.

The calibration process was carried out using yearly values. In order to apply the split-sample technique (Klemes, 1986). To evaluate the model in terms of predicted erosion rates, a subset of six years was chosen for calibration.

The model performance was evaluated qualitatively, with comparison of the graphics of observed and simulated values, and their coefficient of determination, and also using the following quantitative indexes:

Coefficient of efficiency (Nash-Sutcliffe)  $NSE = 1 - \frac{\sum_{i=1}^{n} (p_i - m_i)^2}{\sum_{i=1}^{n} (m_i - \overline{m})^2}$ 

Root mean square error

$$RMSE = \left[\sqrt{\frac{1}{n}}\sum_{i=1}^{n}(m_{i-}p_{i})^{2}\right]$$

Nash–Sutcliffe efficiency can range from  $-\infty$  to 1. An efficiency of 1 corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model.

#### **Results and discussion**

Figure 7 and 8 show the results of the model predictions for the selected years, compared with the measured soil losses, for the CT and GC plots respectively. Both for the CT plot (Fig.7) and for the GC plot (Fig.8) the predicted soil losses overestimated the measured ones, especially for two of the selected years for options 1 and 2, where rainfall erosivity was obtained from the Ovada 10-min rainfall data. The option 2, that considered the variable soil moisture subfactor, provided best results than the option 1, where variable K was used. Soil losses overprediction was reduced (and coefficient of determination increased for the CT plot) when the rainfall erosivity that was used as input data in the model was obtained from hourly data measured at the Cannona centre (Fig.7c). This was especially evident for the GC plot (Fig.8c), where predicted soil losses were highly overestimated for one of the selected years, but in most of cases the predicted soil values were close to the measured ones. The coefficient of efficiency (NSE) and the root mean square error improved moving from option 1 to option 3, but the predictions were not satisfying, as the negative values for NSE demonstrated (Table 1).





Fig.7 – Predicted vs measured soil losses for the CT plot for the three considered options.

# **iMANOTER**



Fig.8 - Predicted vs measured soil losses for the GC plot for the three considered options.

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Fig.9 – Ratio GC/CT of the predicted and measured soil losses for the three considered options.

## **INA NOTE?**

		СТ			GC	
	R <sup>2</sup>	NSE	RMSE	R <sup>2</sup>	NSE	RMSE
			(t/ha)			(t/ha)
Option 1 – K=var, sm=const, R=Ovada	0.3575	-48.6	105.7	0.1238	-90.4	12.9
Option 2 – K=const, sm=var, R=Ovada	0.3408	-7.2	43.1	0.0328	-25.3	6.9
Option 3 – K=var, sm=const, R=Cannona	0.4707	-1.8	25.2	0.1171	-7.1	3.8

Tab.1 – Model performance indexes of the RUSLE2 Excel tool model for annual soil losses in the selected years.

The ability of the model to catch differences among the two considered treatments is analyzed considering the ratio GC/CT of the predicted soil losses, compared with the ratio GC/CT of the measured values (Fig. 9). The annual soil losses measured in GC are about 9 times lower than those measured in CT (SL(GC) = 0.1105 SL(CT), with R<sup>2</sup> = 0.8). The relationship between soil losses predicted in GC and in CT range from 0.1103 to 0.1212 (from 9 to 8.25 lower in GC with respect to CT), with a decreasing coefficient of determination moving from option 1 to option 3. The model maintained a good ability , in the three considered options, in catching differences among treatments. However further tests will be carried out in order to improve its efficiency in predicting annual soil losses magnitude and to complete the calibration process. Then the remaining years of the Cannona database will be used to validate the model in order to apply it in different vineyards.

The first attempts of calibration resulted to be relatively good, especially for the CT plot. However the quantitative indexes showed that the calibration process needs to be improved, to assure a good performance in future simulation. In order to obtain a better performance of the RUSLE2 Excel Tool, the calibration and validation procedure will be applied to the Cannona study case using further calibration options.

#### Conclusions

The Cannona Data Base represents a precious data collection in order to calibrate the RUSLE2 Excel Tool in vineyards, in order to assess the effect of soil management on soil erosion. The results obtained in first attempts of calibration show that a proper calibration of the model is required, especially in situations outside of those where it was developed. Further improvements are needed in the model calibration to assure a good performance of the model in evaluating the effect of soil management on soil erosion risk under different scenarios.

#### Aknowledgments

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superficiali: confronto ed evoluzione delle caratteristiche del terreno e delle acque di ruscellamento superficiale in vigneti con diversa gestione del suolo e della fertilizzazione", years 2000-2014).

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Cordoba, July 12th 2016

To who is might concern,

D. José Alfonso Gómez Calero, Staff Scientist and Director of the Soil Erosion Laboratory of the Instituto de Agricultura Sostenible (IAS) of CSIC, declares that Dr. Marcella Biddoccu, researcher at Instituto per le Macchine Agricole e Movimento Terra (IMAMOTER) of CNR, was in my laboratory for a research stay from June 14<sup>th</sup> 2016 to July 1<sup>st</sup> 2016.

During this stay Mrs Biddoccu carried out work in the research programme "Implementation of RUSLE in Mediterranean vineyards" with myself and the Dr. Gema Guzmán, resulting in an improved strategy for calibrating RUSLE in vineyards under Mediterranean conditions as well as in a preliminary validation of this approach.

The stay of Dr. Biddoccu has been extremely productive and it has provided results for a possible publication in the coming months as well as in new ideas for further collaboration between both laboratories that will be pursued in future project calls.

In case of requiring further information I can be contacted by phone at +34-957-499-252 or by email at joseagomez@ias.csic.es.

Yours sincerely,

José Alfonso Gómez Calero

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