Spatial and temporal evaluation of erosion with RUSLE: a case study in an olive orchard microcatchment in Spain

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ABSTRACT.

Soil loss is commonly estimated using the Revised Universal Soil Loss Equation (RUSLE). Since RUSLE is an empirically based soil loss model derived from surveys on plots, the high spatial and temporal variability of erosion in Mediterranean environments and scale effects provoke that studies evaluating the model on other spatial units such as the microcatchment are necessary. In this study, different topographic and soil surveys were carried out on a microcatchment of 6.7 ha in a mountainous area under no-tillage farming with bare soil to examine spatial and temporal results produced by RUSLE. The height difference of microrelief through GPS measurements was set on a control area in the microcatchment to compare observed erosion and deposition with RUSLE predictions. It was found that erosion points located on zones highly correlates with RUSLE predictions while the distribution of deposition points showed no correlations with RUSLE predictions. Secondly, time series of daily rainfall data were used to calculate annual erosivity and efforts were made to fit rainfall data to an appropriate distribution function. It was found that rainfall distribution fit the Pearson type III distribution function the best. Then, efforts were make to quantify the long term erosion and to check the suitability of land-use and management under different thresholds of tolerance. It was found values of erosivity with a return period of 10 years in the study area generated a mean annual erosion of 5 $t.ha^{-1}.year^{-1}$. On the study scale, RUSLE allowed to locate the most erosive areas and to combine the suitability of the soil land-use and the management with the frequency of the annual erosivity. In addition, an annual sediment delivery ratio of approximately 47 % was estimated for the period of 2005-06.

1. INTRODUCTION

Soil erosion is a serious problem in Spain where 46% of the national territory shows larger rates of soil losses than tolerance values (MMA, 2007). In fact, higher erosion rates than 50 $t.ha^{-1}$/year are expected in mountainous agricultural regions associated to orchard crops such as

Andalusia (MMA, 2007). In this region, there are 1.48 Mha of olive orchards (CAP, 2007) that constitute a key crop in terms of income, employment and environmental impact.

Different studies under several environmental conditions and management have been conducted on small plots to quantify the soil losses (Kosmas et al., 1997; Raglione et al., 1999; Pastor et al., 1999; Gómez et al., 2003; Gómez et al., 2004; De la Rosa et al., 2005; Francia et al., 2006; Gómez et al., 2008a). However, because of high variability that characterizes Mediterranean environments, soil erosion varies considerably over space and time and in most cases, it is unsuitable to extrapolate these measures to other spatial units where different hydrological and erosive processes take place. In Andalusia, 71.4 % of farmlands shows mean size between 2.4 ha and 18.0 ha (CAP, 2003). Thus, studies for predicting temporal and spatial distributions of soil erosion at the microcatchment scale would improve the strategies of environmental management since not only are they carried out on real farms but the planning of control measures also require the compromise of a low number of farmers. Therefore, the overall objective of this study was to look for and/or improve management strategies of olive orchards to reduce soil erosion. The first step to achieve this objective was to evaluate temporal and spatial erosion risk on the microcatchment scale.

Soil loss is commonly predicted using empirical model as the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1965) because of their simple structure and ease application. In Spain, the National Map of Erosive States and the National Map of Deserfication Risks have been carried out through the USLE and the revised version RUSLE (MMA, 2007). Soil erosion from an area in Spain is simply estimated as the product of empirical coefficients originally derived from field observations in U.S. Those empirical coefficients derived from field observations in U.S have rarely been verified according to experimental and scale conditions of Spain because of the difficulties in data collection (Amore et al., 2004).

The recent development of GPS techniques provides a wide range of possibilities to analyze temporal and spatial dynamics of erosion and sedimentation (Higgit and Warburton, 1999). The accuracy of GPS has been improved and it appears applicable to the continuously monitoring small and slow morphology changes on the earth surface (Wu and Cheng, 2005). Moreover, the equipment has become progressively more economical and easier to use in geophysical research such as gully erosion monitoring (Wu and Cheng, 2005; Cheng et al, 2007); morphmetric estimates of coarse fluvial sediment transport (Brasington et al., 2003); morphological change of slides (Malet et al., 2002); and monitoring olive tree movements caused by continuous tillage erosion (Ramos et al., 2007).

Conventional methodologies to observe soil losses were based on the measurements from the top soil levels through pins or stakes as references (Haigh, 1977; Sarre, 1984). Topographic instrumentation as thedolites and GPS have allowed to improve the accuracy and maintain the use of witnesses that are difficult to keep in field due to management operations (Laguna, 1989; Wessemael et al., 2006). In addition, GPS does not require a direct line of sight between the receiver and the station, which is very useful considering the lack of visibility through the olive trees.

Long term analysis of the temporal context is essential for making correct environmental decisions. Renschler et al. (1999) carried out an approach to examine the temporal variability of the soil loss ratios through probabilistic analysis of the quantiles of daily erosivity values under different agricultural crop rotations in basins of Andalusia (southern Spain). In this study, this approach was applied to evaluate the impact of soil management on annual erosion rates at microcathment scale. The spatial varibility of RUSLE predictions is analyzed with two years GPS measurements set on a control area in the microcatchment. In addition, the microcatchment was equipped to acquire data of runoff, peak flows and sediment loads which were used to compare rates of erosion and yield in a period of a year.

2. MATERIAL AND METHODS.

2.1. Study site.

Setenil microcatchment is situated in the province of Cadiz, Spain (36.88 ºN, 5.13 ºW). The drainage area is 6.7 ha (Fig. 1), with a mean elevation of 782 m and mean slope of 10.3 %.

Figure 1.

The type of climate is Mediterranean with Atlantic influences. The orographic effects influence on the rainfall spatial variability so that the annual mean values in gauges separated about 20 km vary from 600 mm to 1100 mm (Castillo, 2002). The hottest month is July (average temperature 25.1 ºC) and the coldest January (7.1 ºC).

The soil type in the catchments is Luvisol (FAO classification) with an average depth about 1.5 m. The soil texture is loamy sand and the average surface soil organic matter content is 0.9 %. In the microcatchment, there are two well-differenciated areas: in the highest zone (1.4 ha) corresponding to an old area with cereals, young olive trees are located ; the rest is occupied by 20 years olive trees spaced 7 x 7 m apart (Fig. 1). The “conventional tillage” has been the soil management commonly applied, but the annual tillage operations have been reduced progressively. For the study period, “no tillage” operations were implemented, and two weed controls per year in October and March using herbicides around every tree in the rows are carried out. However, tillage operations were applied in April and May 2004 for the young olive trees to improve the development of the young olive trees.

2.2. Soil erosion measures.

2.2.1. GPS surveys: control points to observe erosion and deposition processes.

A control grid of 483 points (Fig. 2) on the area with older olive trees, has been set in the study area. Two topographic surveys were carried out in September 2004 and September 2005 in this area. The surveys were performed with a GPS system- Leyca 1200 with planimetric and altimetric precision of 1 cm $\pm$ 2 ppm and 2 cm $\pm$ 2 ppm expressed as root square mean error (RMSE). Thus, the probability for altimetric measurements to take a bigger error than 2 cm (RMSE) is 67 %. The theory of the error in the sum of two magnitudes verifies that its error is the sum of errors of both magnitudes. Therefore, the square of root square mean error, corresponding to the sum σ_s of two magnitudes (A_s and B_s) when the measurements were unbiased and are not correlated, will be equal to the sum of the root square mean errors of A_s and B_s, defined as a_s and b_s, respectively (Eq. 1).

$$\sigma_s = \sqrt{a^2{}_s + b^2{}_s} \quad \text{(Eq. 1)}$$

If A_s represents the topographic mesurements in 2004 and B_s in 2005, the Eq. 1 indicates that the RMSE of the altimetric differences (with a confidence level of 67 %) is 2.8 cm. If the error is 4.0 cm, the level of confidence is risen to 84 % according to Gauss distribution of errors. Thus, when topographic differences (B_s –A_s) are bigger than 4 cm or less than 4 cm, we will have more than 80 % of confidence in order to efficiently characterize areas where the deposition and erosion are dominant phenomena. In addition, measurements were taken on a 10 m grid to include the whole area according to tree spacing of 7 m.

Figure 2

The topographical analisys was only carried out on the area with older olive trees due to the different managment and the effects of tillage on the highest zone in the catchment.

2.2.2. Rainfall, runoff and sediment load

In April 2005, a gauging station was built at the outlet of the microcatchments to monitor rainfall, runoff and sediment concentration data. Rainfall was measured with one gauge (Hobo Event 7852M), the discharge was obtained by flumes of critical flow depth (Clemmens et al., 2001)., where the water level was measured by an ultrasonic sensor (Milltronics Ultrasonics). When the water level rises to a predetermined level, the automatic sampler (ISCO 3700C) turns on and fills a bottle at 10 min intervals. Althought the period of data acquisition was interrupeted for 83 days, the calibration of AnnAGNPS model (Bingner and Theurer, 2003) with 22 events allowed to calculate total loads of sediments during April 2005-April 2007 (Taguas et al., 2009). These soil loss values and its mean value were used for the quantitative exam of RUSLE predictions as well for the estimation of sediment storage and the sediment delivery ratio (SDR) in the catchment.

2.3. RUSLE

RUSLE was conceived to predict long-term average annual soil loss (*A*) as the product of six parameters:

$$A=R.K.LS.C.P \qquad \text{(Eq. 2)}$$

Where A is computed in t.ha^{-1}yr^{-1}; R is the rainfall erosivity factor (MJ.mm.ha^{-1}.h^{-1},yr^{-1}); K represents the soil erodibility (t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}); L is the slope lenght factor and S is the slope gradient factor (dimensionless); C is a cover management factor (dimensionless) and P is a support practice factor (dimensionless).

Slope lenght factor LS

LS values were delineated from the DEMs derived from GPS surveys (cell size 10 m) using the tools Raster Calculator of Arc Map (ESRI, 2002) according to Eqs. 2 and 3:

$$LS = \left(\frac{\lambda}{22.1}\right)^{0.3} \cdot \left(0.065 + 0.0454 \cdot S + 0.0065 \cdot S^{2}\right) \text{ if } S > 9\% \qquad \text{(Eq 2)}$$

$$LS = \left(\frac{\lambda}{22.1}\right)^{0.3} \cdot \left(\frac{S}{9}\right)^{1.3} \text{ if } S < 9\% \qquad \text{(Eq. 3)}$$

where S is the slope (%) and λ is the lenght of the slope (m) obtained from the computation of the grid of accumulated areas with Hydro Tools of ARCGIS 9.2. (ESRI, 2002) divided by the cell size (10 m).

Rainfall erosivity, R

The erosivity for the period of September 2004-September 2006, corresponding to the analysis interval of the topography, was calculated using the relationships estimated by Domínguez-Romero et al. (2007) for the daily erosivity (E_d) in the province of Cadiz (Eq. 3). The catchment was equipped with a rainfall gauge in April 2005. Thus, the observed daily rainfall and available rainfall data from the nearest meteorological station in Olvera (5º 15 ´31´´ W, 36º 55´ 59´´ N, DGAP – Junta de Andalucía) which were well-correlated (r = 0.86) with observed rainfall were used.

$$E_d = 0.1449 * P^{1,8967} \qquad \text{(Eq. 3)}$$

Constant grids with the annual values of erosivity were created using Arc Catalog (ARCGIS 9.2., ESRI, 2002)

In addition, long term daily rainfall record for Setenil (5º 10 ´57´´ W, 36º 51´ 51´´ N; National Meteorological Institute, series 1950-1999, Table 1) was obtained for the exam of temporal variation of the erosivity (the rates of soil loss). Since only 8 years have complete rainfall record, additional analysis was performed to check if years with missing records in July and August can be included given the situation that the missing records in July and August were low enough that they can be neglected. Rainfall depth less than 10 mm was usually excluded for the calculation of annual erosivity. Therefore, all available July and August rainfall data were analyzed. It was found that only one rainfall event greater than 10 mm occurred in July, two events with greater value of 10 mm occurred in August. This analysis justified the inclusion of years with missing July and August records. As a result, a record of 14 years in Setenil station was considered (Table 1)

Table 1. Rainfall accumulated from daily data series in Setenil station according to the number of available months and calculated *R* values.

Year	Num. Available Months	Accumulated rainfall (mm)	R (Mjmmha-1h-1yr-1)
1950	10	509.5	
1957	**10***	**1314.7**	**577.4**
1958	10	1234.7	
1959	9	1386.7	
1960	9	2426.1	
1961	10	1510.1	
1962	**10***	**1927.8**	**1514.9**
1963	**11***	**2670.4**	**1710.2**
1964	9	1193.4	
1965	**12**	**1510.9**	**725.7**
1966	**12**	**1145.4**	**508.2**
1967	9*	951.9	
1968	**11***	**1574.1**	**806.8**
1969	**10***	**2162.7**	**1207.0**
1970	9*	595.7	
1971	10	1554.8	
1972	**10***	**1457.3**	**455.6**
1973	9	869.7	
1974	9	815	
1975	9	1173.5	
1976	9*	1540.7	
1977	9	1054	
1978	9*	1161.5	
1979	9*	1470	
1980	**10***	**568**	**193.9**
1981	8	432.7	
1982	10	495.5	
1983	6	521	
1984	9*	514	

1985	6	569	
1986	**12**	**580**	**166.4**
1987	**12**	**578.8**	**194.3**
1988	**12**	**574**	**189.3**
1989	8	886	
1990	6	176	
1991	3	156.1	
1992	10	668.1	
1993	8	248	
1994	**12**	**359**	**88.7**
1995	11	472.2	
1996	**12**	**996**	**244.9**
1997	11	628.8	
1998	10	316.2	
1999	9	254.3	

(*) These data were considered when only July and/or August missed.

Soil erodibility, K

Soil samples were collected and surveys were conducted in July and August of 2004 for checking the soil properties such as textureorganic matter, saturated hydraulic conductivity and bulk density (Table 2). The structure was evaluated in field through the exam of 4 profiles. The locations where samples were collected were recorded with a GPS unit. Approximately 2-5 samples/ha were randomly taken in the hillslopes of the cathment (Table 2). Maps or grids of soil attributes were done through the interpolation of collected point values according to the methodology of the Inverse Distance Weighted (IDW) with Spatial Analyst of ARCGIS 9.2. (ESRI, 2002). Finally, the tool Raster Calculator allowed to compute the soil erodibility map using following equation in RUSLE manual (Eq. 4 - Renard et al., 1997).

$$K = (2.71\cdot 10^{-4}\cdot(12-a)\cdot M^{1.14} + 4.20\cdot(b-2)+3.23\cdot(c-3)/100 \qquad \text{(Eq. 4)}$$

where *M =(100 - %clay).(%silt + %(fine sand))*; *a* = organic matter content (%); b = representative code of the soil structure type (dimensionless); c = code of the soil profile permeability (dimensionless)

Table 2. Soil properties, methodologies and number of samples considered for the erodibility calculation.

Properties	Methodology / Survey	Samples (n)
Texture	Robinson pippete (Soil Conservation Service, 1972)	12

%OM	Walkley-Black (Nelson and Sommers, 1982)	12
Ksat ($cm^{-1}.h$)	Philip (1993)	30
BD ($g.cm^{-3}$)	Mass / Volume of clods with wax to measure their submerged weight	30

Cover and support practice factors, C and P

The C factor is dependent on the prior land use, the canopy and surface cover, the surface roughness and the soil moisture (Renard et al., 1997). In this case, a C value of 0.41 was chosen according to the olive tree land-use and no till management (Gómez et al., 2003).

Finally, the management factor was not considered since there are no support practices in the catchment (P = 1).

2.4. Statistical analysis.

2.4.1. Spatial exam of RUSLE-predictions and the erosion/deposition areas

Firstly, erosion maps generated by RUSLE application were examined to characterize spatial variability of the potential erosion in the hillslopes. Secondly, the RUSLE values at measurement points where soil loss and deposition are evident processes - elevation differences $\leq$-4.0 cm in the case of erosion and elevation differences $\geq$+4.0 cm in the case of deposition- were checked to evaluate the model results. The histograms of the RUSLE predictions and the measured erosion/deposition at grid points, and the edafological and topographical features statistics were compared. Finally, the measures of the load of sediments in the cathment were also used to evaluate the predictions of the annual potential erosion as well as sediment delivery ratios.

2.4.2. Long term evaluation of soil erosion.

Annual values of erosivity were calculated from data series in Setenil station (5º 10 ´57´´ W, 36º 51´ 51´´ N; National Meteorological Institute, series 1950-1999). A simple exploratory analisys was carried out, examinig the statistics and the form of the distribution. The Eq. 5 shows the conventional equation that relates the return period (T) or recurrence interval with a hydological quantile (usually rainfall depth or flow, Chow et al., 1988). Although this expression is commonly used for the design of hydrological systems, it can be used to compute any parameters related to rainfall storms such as the rainfall erosivity (Wischmeier, 1962):

$$T = \frac{1}{1-F(X)} \qquad \text{(Eq. 5)}$$

where: *F(X)* is the accumulated function of probability/frequency and *X* is the hydrological quantile, in this case, annual erosivities (*R*).

The exceedance probability or accumulated frequency *P(x< xi)* for the series of erosivity (Table 1) were calculated through Weibull´s equation (Eq. X, a = 0) and Gringorten´s equation (Eq. 6, a = 0.44).

$$P(x \le x_i) = \frac{m-a}{n+1-2a} \qquad \text{Eq. 6}$$

Where: m is the order or place of the value x_i and n is the total number of the data.

These values were used to adjust the continous functions Gumbel´s (Eq. 7) and Pearson´s type III (Eq. 8) that supported the best fits (Abramowitz and Stegun, 1965). Kolmogorov´s test (with 5 % significance level) allowed to check that the selected type of distributions were suitable to the values of probability.

$$F(x) = P(X \le x) = e^{-e^{-\alpha(x-\beta)}} \quad -\infty \le x \le \infty \qquad \text{Eq. 7}$$

$$F(x) = P(X \le x) = \frac{1}{\alpha\Gamma(\beta)} \int_{\gamma}^{x} e^{-\left(\frac{x-\gamma}{\alpha}\right)} \left[\frac{x-\gamma}{\alpha}\right]^{\beta-1} dx \qquad \text{Eq. 8}$$

Where: α, β, γ are the form parameters of the distributions and $\Gamma(\beta)$ is a function gamma.

Finally, the correlation coefficient of observed-adjusted values (R) and the root mean square error (RSME) were evaluated to justify the best fit, obtaining the quantiles of the annual erosivity for different return periods (2, 5, 10 and 15 years). This quantiles were used to calculate potential erosion and to assess the land-use and the management practices in the cathment according to the temporal varibility of rainfall.

3. RESULTS

3.1. Spatial evaluation of soil erosion.

Table 4 shows a summary of the values of erosion for both study periods. As is observed the *R-value* for the period 2004-2005 was 340.4 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$ while 733.9 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$ were calculated for the campaign 2005-2006. The annual rainfall was 279 mm and 553 mm for 2004 and 2005, respectively. *LS-factor* distributions obtained from both topographic surveys were very close, although smaller values were calculated for the period 2005-2006. The spatial mean value of *K-factor* was 0.030 $t.h.MJ^{-1}.mm^{-1}$ with a variation coefficient of 23.3% (Table 4). As a result, the annual erosion for the period 2004-2005 was 1.5 $t.ha^{-1}.year^{-1}$ while 3.2 $t.ha^{-1}.year^{-1}$ were calculated for the period 2005-2006. Extreme values were located next to the channel as a result of the maximum values of *LS-factor* while higher areas in hillslope-half showed the lowest values of erosion (Fig. 2a-2b).

Table 4. Rates of erosion and values of R-factor, LS-factor and K-factor in the study area for the periods 2004-05 and 2005-06.

	Erosion ($t.ha^{-1}.year^{-1}$)		*R- factor* ($MJ.mm.ha^{-1}.h^{-1}$)		*LS- factor*		*K- factor*
	2004-05	2005-06	2004-05	2005-06	2004-05	2005-06	($t.h.MJ^{-1}.mm^{-1}$)
M	1.47	3.17	340.4	733.9	0.32	0.17	0.030
Dv	1.55	3.28	-	-	0.30	0.26	0.004
Min	0.00	0.00	-	-	0.00	0.00	0.016
Max	10.20	22.10	-	-	2.04	2.18	0.038

Figure 2a shows the distribution of erosion and deposition according to the differences of height (measurements period 2005-2006 – measurements period 2004-2005) in the 483 control points in the old olive tree area according to a larger confidence level than 80 %. As is observed, from 483 control points only 30 points were considered as places with evident soil losses and 56 points, in the case of deposition. Erosion points were mainly located in rills situated in the half of hillslopes and near the stream while depositon points were concentrated next to the outlet and the boundary of the field (Fig. 3a). On the other hand, erosion points were mainly located in the half of hillslopes and near the stream on zones with larger *K-factor* and *LS-factor* while deposition points were concentrated next to the outlet and on the boundary of the field, in zones with lower *K-factor* and larger *LS-factor* (Table 5). These results can be explained by the observed values of some soil and topographical features in erosion and deposition points (Table 6).Thus, the deposition points were situated in areas with higher values of saturated hydraulic conductivity (19.7 cm/h) than study area (15 cm/h) while erosion points tended to place in areas with higher slopes (6.8º versus 6.4º) and bulk density (1.69 versus 1.66 g/cm^3) and lower values of saturated hydraulic conductivity (13.5 cm/h). The texture as the organic matter showed very low variability in the catchment.

Table 5. Statistics of K-factor, LS-factor (period 2004-05) and rates of erosion (period 2004-05) for the erosion points, depositon points and for the study area (M= mean; Dv= standard deviation; Max = maximum; Min= minimum).

	Sta.	Study area	Erosion points	Deposition points
K-Factor (t.h.MJ^{-1}.mm^{-1})	M	0.030	0.032	0.027
	Dv	0.004	0.002	0.004
	Max	0.038	0.035	0.033
	Min	0.016	0.027	0.017
LS-Factor	M	0.32	0.38	0.36
	Dv	0.30	0.49	0.35
	Max	2.04	1.91	1.58
	Min	0.0	0.00	0.00
RUSLE estimates (t.ha^{-1}.y^{-1})	M	1.47	1.81	1.56
	Dv	1.55	1.65	1.86
	Max	10.20	8.57	8.30
	Min	0.00	0.22	0.00

Figures 3.a and 3.b.

In addition, the histogram of the values of RUSLE on the erosion points and on the deposition points have been compared with the distribution of RUSLE predictions in the study area (Fig. 3). As is observed in Table 5 and Figure 4, the erosion points tended to place areas with a erosion range between 1.5 and 5 t.ha/year, which explains a higher mean value of soil losses on erosion points.In the case of deposition, both histograms presented a similar distribution of intervals.

Figure 4. **Table 6. Statistics of drainage area (A), local slope (β), saturated hydraulic conductivity (Ksat) and bulk density (BD) (period 2004-05) for the erosion points, depositon points and for the study area (M= mean; Dv= standard deviation; Max = maximum; Min= minimum).**

Attribute	Sta.	Study area	Erosion points	Deposition points
A (ha)	M	0.0	0.1	0.1
	Dt	0.3	0.4	0.5

	Min	0.0	2.1	0.0
	Max	6.7	5.0	4.1
β (º)	M	6.4	6.8	6.5
	Dt	1.8	1.5	1.9
	Min	0.0	3	2.4
	Max	14.8	9.3	11.9
Ksat (cm/h)	M	15.0	13.5	19.7
	Dt	10.0	10.5	10.7
	Min	2.0	3.9	3.3
	Max	44.0	40.5	42.9
BD (g/cm3)	M	1.66	1.69	1.66
	Dt	0.09	0.09	0.07
	Min	1.11	1.41	1.49
	Max	1.90	1.89	1.86

3.3. Assessment of the suitability of the management in terms of the temporal variation rainfall

Table 7 shows the results of adjusting tests of accumulating distribution functions. Although the value of discondance (D) calculated for Kolmogorov-Smirnoff ´s test was lesser than the statistics *K* (significance level = 5%) for all cases, the values of exceedance probability calculated by Gringorten´s equation and the fit of Pearson Type III function provided the best adjusting with a RMSE of 102.5 $MJ.mm.ha^{-1}.h^{-1}$ and a coefficent of correlation between observed and estimated values (R) of 0.98.

Table7. Summary of distribution function fittings for the annual erosivities: root square mean error (RMSE), coefficient of correlation between observed and predicted values (R), value of discordance (D) for Kolgorov-Smirnoff test´s. ($K_{5\%}$= statistic K for the test with a significance level of 5%; W = exceedance probability of Weibull´s formula; W = exceedance probability of Gringorten´s formula)

	Gumbel (Form. W)	Gumbel (Form. G)	Pearson TIII (Form. W)	Pearson TIII (Form. G)
RSME ($MJ.mm.ha^{-1}.h^{-1}$)	123.5	122.4	139.41	102.5
R	0.97	0.97	0.98	0.98
D statistic ($K_{5\%}$=0.349)	0.165	0.138	0.170	0.170

Finally, Table 8 shows the quantiles of R for the return periods 2, 5, 10 and 15 years and the corresponding values of potential erosion. As is observed the annual erosivity with the recurrence period of 10 years (equivalent to an accumulated frequency of 0.9) implies larger soil losses than 5 $t.ha^{-1}.year^{-1}$ and higher soil losses than 10 t/ha.year in 10% of the area. (Fig. 5b)

Table 8. Values of R-factor for the return periods of 2,5, 10 and 15 years with the corresponding values of erosion derived from RUSLE in the catchment (mean, maximum, minimum and standard deviation; F(R) = Accumulated probability of R-factor)

T (years)	R ($MJ.mm.ha^{-1}.h^{-1}$)	Mean Erosion ($t.ha^{-1}.y^{-1}$)	Max Erosion ($t.ha^{-1}.y^{-1}$)	Min Erosion ($t.ha^{-1}.y^{-1}$)	Dv ($t.ha^{-1}.y^{-1}$)
2 ; F(R) = 0.5	473.5	2.0	19.2	0.0	2.7
5; F(R) = 0.8	952.4	4.1	38.5	0.0	5.3
10; F(R) = 0.9	1299.8	5.6	52.6	0.0	7.3
15; F(R) =0.93	1501.2	6.5	60.7	0.0	8.4

Figure 5.

4. DISCUSSION

In this study, two topographic surveys were conducted to analyze the height variations in the cathchtment. It was found that the highest values of erosion derived from RUSLE were located on measurement points with evident soil losses. It was found that those places have the highest slope and the lowest infiltration. Deposition points from survey were not verified from RUSLE predictions because RUSLE does not account for deposition (Wishemeier, 1976). However, it was found that the distribution of deposition points was well-explained by higher values of saturated hydraulic conductivity. The discontinuation of the generation of runoff in Mediterranean areas where slopes behave as a patchwork for runoff, and runoff areas under different combinations of topographical, edafological and land-uses properties (Cerdá, 1998; Calvo-Cases et al.; 2003) could justify the observed pattern

Sediment load calculated in the catchment for the period September 2005- September 2006 were 1.1 $Mg.ha^{-1}$ (Taguas et al., 2009), which means an annual sediment delivery ratio for the whole catchment of 47.2 %. Authors such as Gómez et al. (2008c) have determined in a small catchment (8 ha) with olive tree land-use under conventional tillage an annual sediment delivery ratio of 17 % and mean soil losses of 4.3 $Mg.ha^{-1}.year^{1}$. Schoorl and Vedkamp (2001) estimated a sediment delivery ratios of about 90%, and soil loss of 3 t ha^{-1} yr^{-1} for olive orchard land use through application of the LAPSUS model (Schoorl et al., 2002). Despite the high variation of sediment delivery ratio values, the annual erosion rates provided by RUSLE are comparable to soil losses observed in the cacthment and rates given by others authors (Pastor et al., 2001; Francia et al., 2006; Gómez et al., 2008a). Amore at al. (2004) also concluded that different experimental conditions (plot or field areas) which were originally used to develop models such as WEPP and USLE- were suitable for estimating the eroded soils.

The common or expected values of erosion in olive groves of the Mediterranean area is a recent controversial issue (Fleskens and Stroosnijder, 2007; Gómez et al., 2008b). Fleskens and Stroosnijder (2007) remarked that the low frequency of intense rainfall events determine the annual erosion. However, the precipitation in the Mediterranean area shows an extreme variability in space and in time. In fact, in Andalusia, the values of mean annual rainfall vary from 200 to 2000 mm (CMA, 2009) and mean annual erosivity vary from less than 50 to 10000 $MJ.mm.ha^{-1}.h^{-1}$ (CMA, 2009),. The annual variations are also very substantial as is observed in rainfall data (Table 1) as well as response catchments (Taguas et al., 2008). Therefore, mean erosion rates should not be taken as a indicator of the real erosion processes (González-Hidalgo et al., 2009) so the use of climatic average values for analyzing soil erosion is debatable (González-Hidalgo et al., 2007). In fact, González-Hidalgo et al. (2007) recommended the application of magnitude-frequency analisys from the temporal sequences of events and the need of temporal context for a correct evaluation of erosion. These type of rainfall analisys were conceived since the origin of USLE to evaluate soil loss (Wischmeier, 1962; Burwell and Kramer, 1983; Zuzel et al., 1993), however, the main limitation is the lack of long term data series. In fact, in this study intensity rainfall data with smaller duration of a day were not available. Although the role of the severe storms can be very important, the annual scale allows to consider the indirect effect of moisture conditions charactering the hydrological period and the power associated to the whole storms occurred (included extreme events). In addition, the frequency analysis of the erosivity not only does it allow to standardise the effects of rainfall when the suitability of land-uses or soil management in different areas are compared and to design structures for the soil protection (Larson et al., 1997) but it could also combine the impact of number of rainfall days with different intensities values.

Soil loss per year between 5-10 $t.ha^{-1}.year^{-1}$ for soil depth of more than 1 m is acceptable (Schertz, 1983). However, higher soil depth than 1 m is not usually present in the areas where the olive groves are cropped. Therefore, our results indicate that a recurrence time of 5 years means serious soil losses since higher rates than 5 $t.ha^{-1}.year^{-1}$ are expected in 20% of the catchment area. The use of cover crop is recommended (Gómez et al., 2008a), especially in areas located in the middle of hillslope with the biggest slope values.

5. CONCLUSIONS

1. In our study the highest values of erosion derived from RUSLE were located on points with evident soil losses according to the measurements of two GPS surveys which illustrated the potential of RUSLE for evaluating the areas with the highest risk of erosion in a olive orchard microcathment.

2. The mean values derived from RUSLE in the catchment were comparable to the values of sediment load observed at the outlet and to values of erosion rates for the same land-use in the Mediterranean area referenced by other authors. Although there was no values of eroded soil in the hillslopes, an annual sediment delivery ratio of 47.2 % for the period september 2005-september 2006 was calculated.

3.- The high variation of annual rainfall and the erosivity values and the need of providing a context temporal in soil loss estimates in the Mediterranean area justify the application of the frequency analysis instead of use of mean values. In this case, the values of exceedance probability for the annual erosivities calculated by Gringorten´s equation and the fit of Pearson Type III function provided the best adjustment.

4. Our results suggest that a recurrence time of 5 years means serious soil losses since higher rates than 5 $t.ha^{-1}.year^{-1}$ are expected in 20% of the catchment area. The use of cover crop is recommended in areas located in the middle of hillslope where the biggest slope values are found.

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TABLES CAPTIONS

FIGURE CAPTIONS

Fig.1. Location of the microcatchment in Spain (up-left) and situation of the microcathment in Gaudalporcun basin (up-right). Limits of the catchment on the aerial ortophotography (below-left) and view of hillslopes (below-right).

Fig. 2. Control points grid in the cachtment: only the area with older olive trees, has been set in the study area since tillage operations were carried out in the area with young olive trees.

Fig. 3 (up). Distribution of RUSLE estimates for the period 2004-05 with the evaluated erosion and depositon points. (Down) Distribution of RUSLE estimates for the period 2005-06.

Fig. 4. a) Hystogram of the RUSLE estimates in the study area; b) Hystogram of the RUSLE estimates in the erosion points; c) Hystogram of the RUSLE estimates in the deposition points.

Fig. 5. RUSLE estimates calculated for the annual erosivities with return periods of 2, 5, 10 and 15 years.

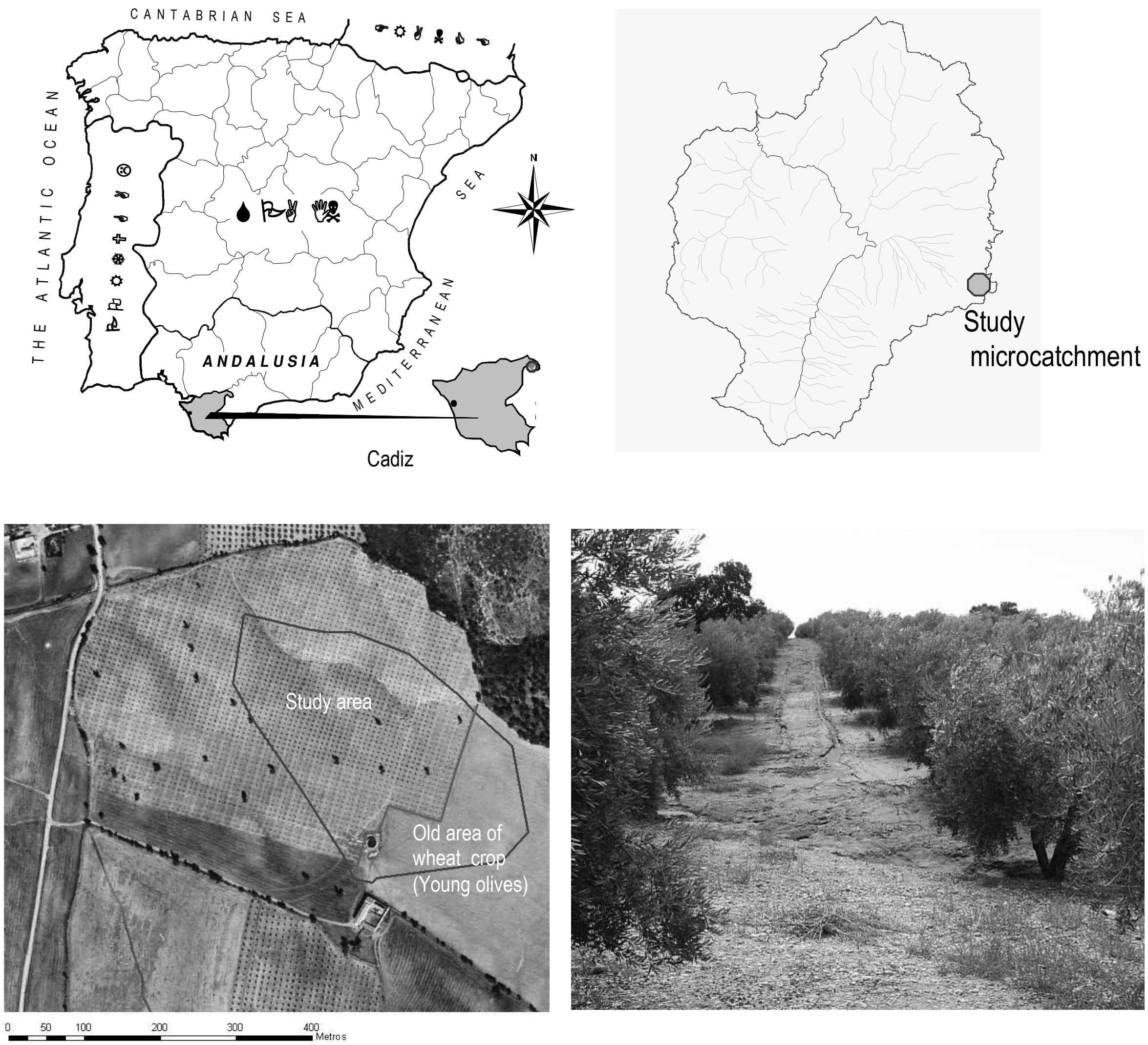
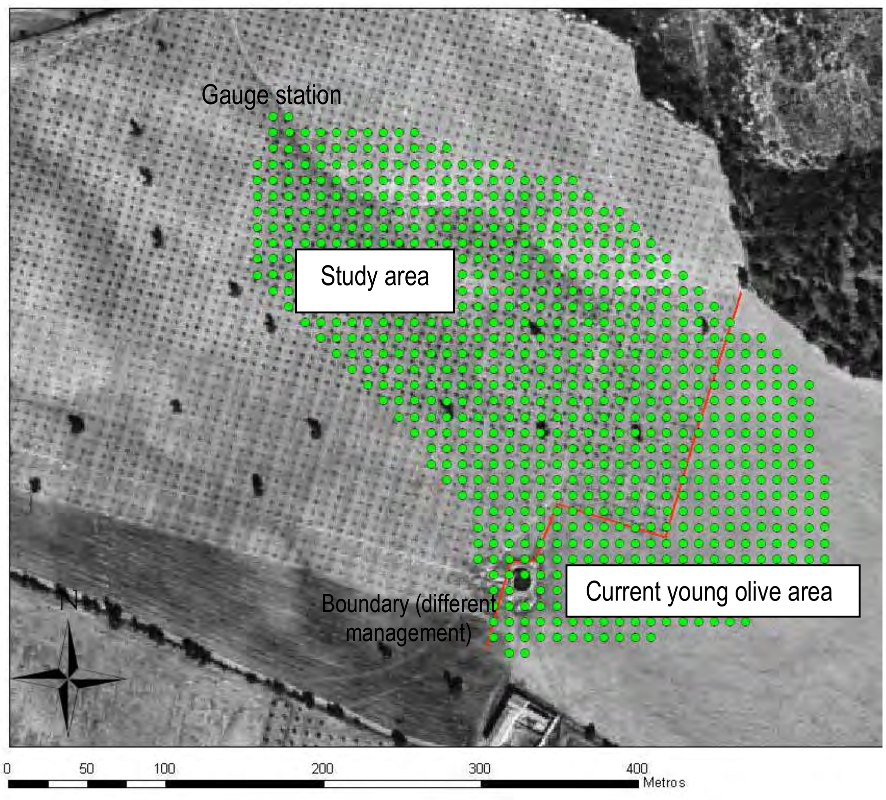


Fig.1. Location of the microcatchment in Spain (up-left) and situation of the microcathment in Gaudalporcun basin (up-right). Limits of the catchment on the aerial ortophotography (below-left) and view of hillslopes (below-right).



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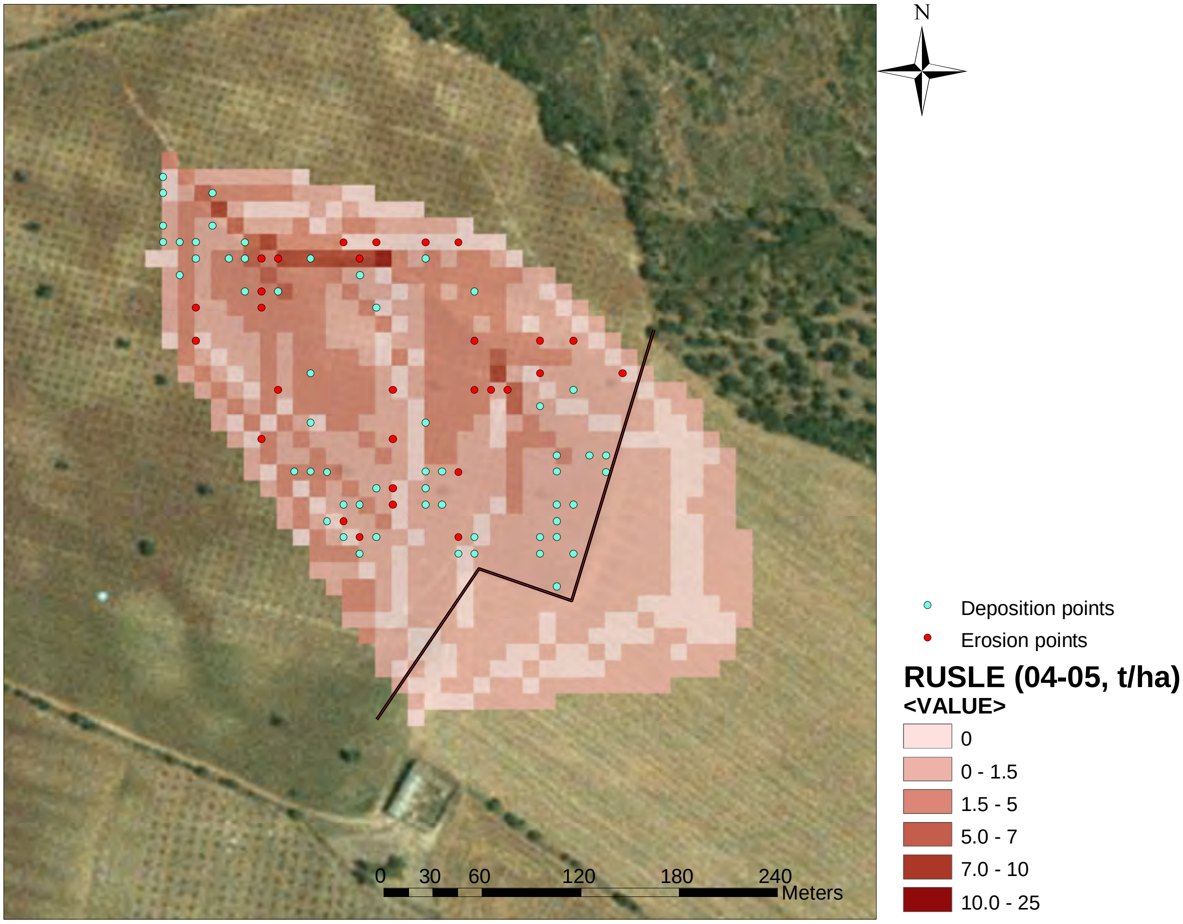
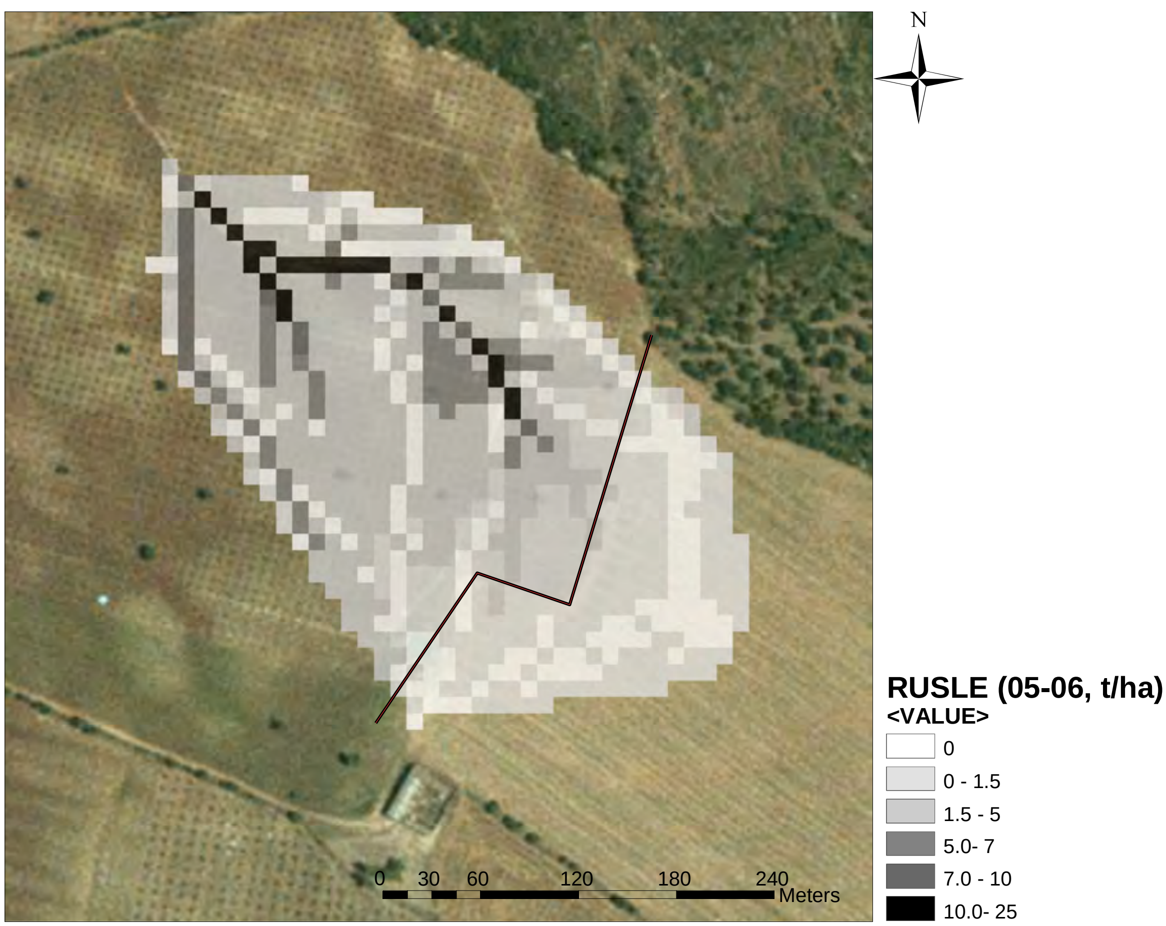
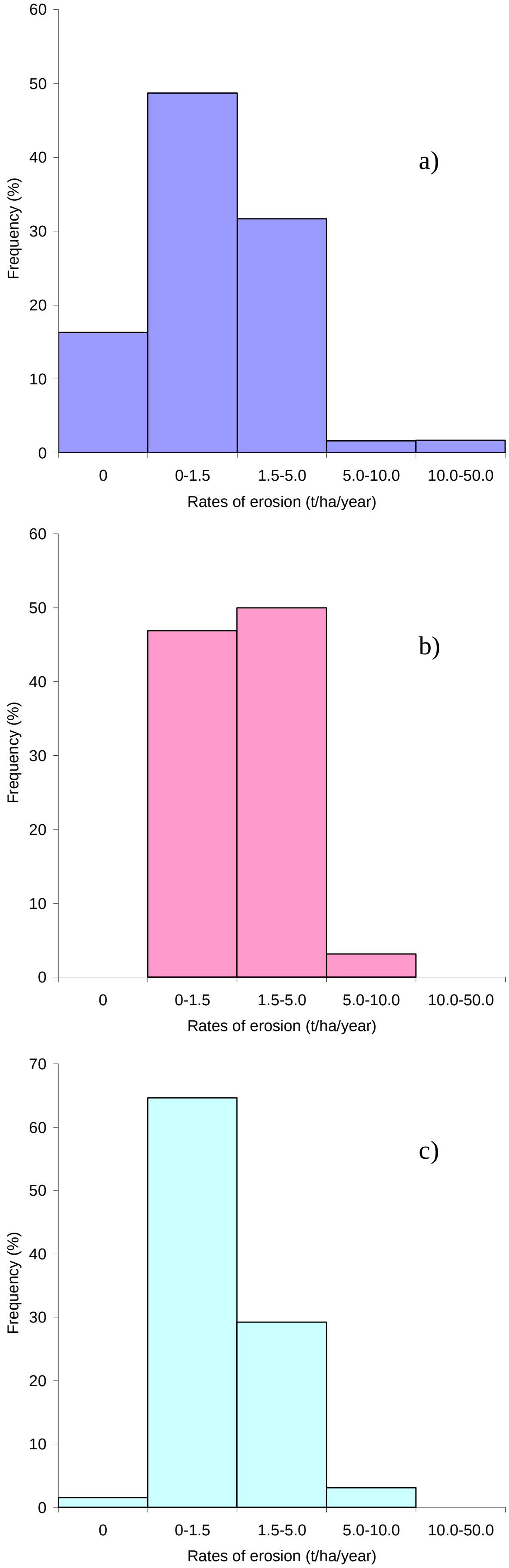
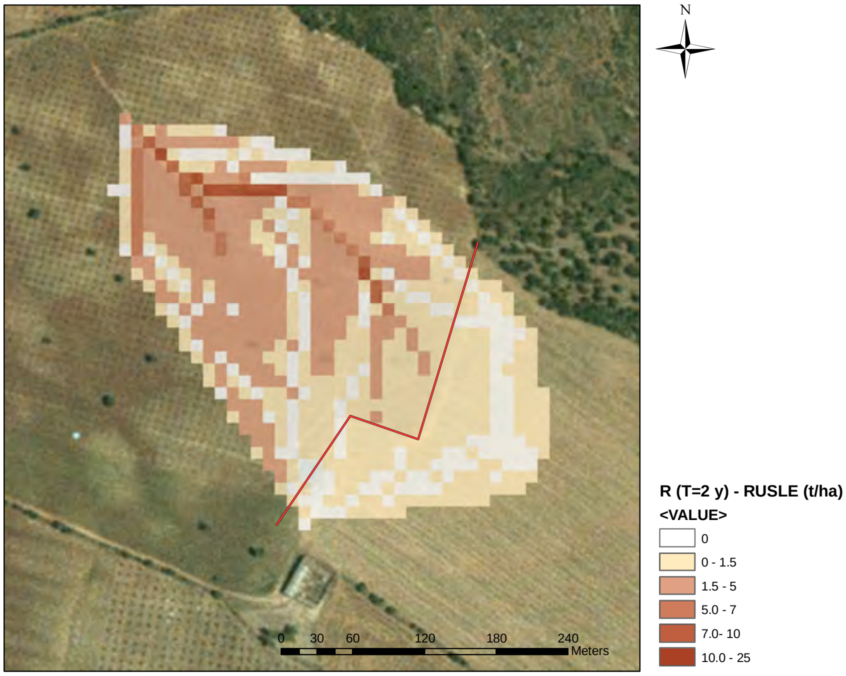
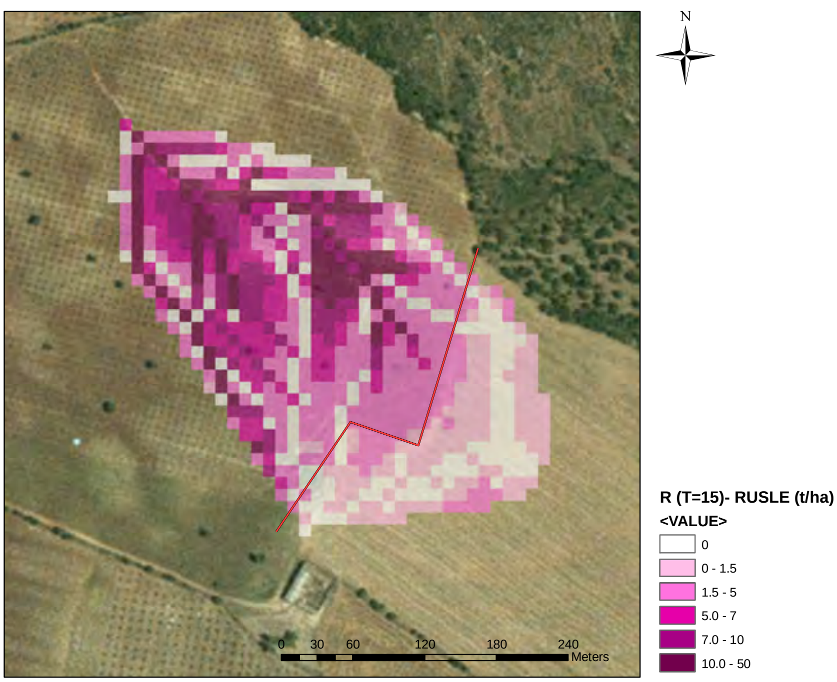

N
0 30 60 120 180 240
Meters
Deposition points
Erosion points
RUSLE (04-05, t/ha)
<VALUE>
0
0 - 1.5
1.5 - 5
5.0 - 7
7.0 - 10
10.0 - 25


N
0 30 60 120 180 240
Meters
RUSLE (05-06, t/ha)
<VALUE>
0
0 - 1.5
1.5 - 5
5.0- 7
7.0 - 10
10.0- 25


a)
Frequency (%)
0
10
20
30
40
50
60
0
0-1.5
1.5-5.0
5.0-10.0
10.0-50.0
Rates of erosion (t/ha/year)
b)
Frequency (%)
0
10
20
30
40
50
60
0
0-1.5
1.5-5.0
5.0-10.0
10.0-50.0
Rates of erosion (t/ha/year)
c)
Frequency (%)
0
10
20
30
40
50
60
70
0
0-1.5
1.5-5.0
5.0-10.0
10.0-50.0
Rates of erosion (t/ha/year)


N
0 30 60 120 180 240
Meters
R (T=2 y) - RUSLE (t/ha)
<VALUE>
0
0 - 1.5
1.5 - 5
5.0 - 7
7.0- 10
10.0 - 25


N
0 30 60 120 180 240
Meters
R (T=15)- RUSLE (t/ha)
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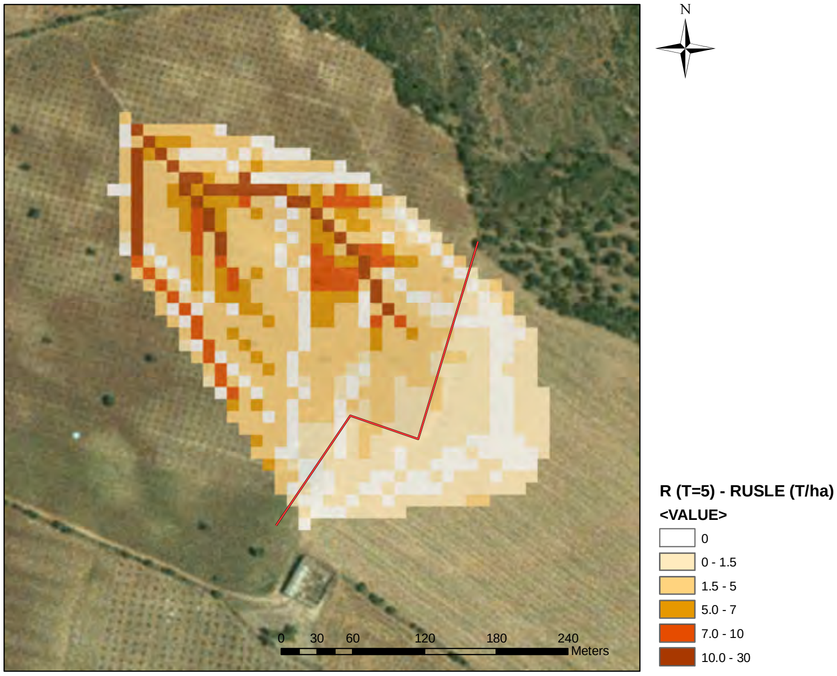
1.5 - 5
5.0 - 7
7.0 - 10
10.0 - 50


N
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Meters
R (T=5) - RUSLE (T/ha)
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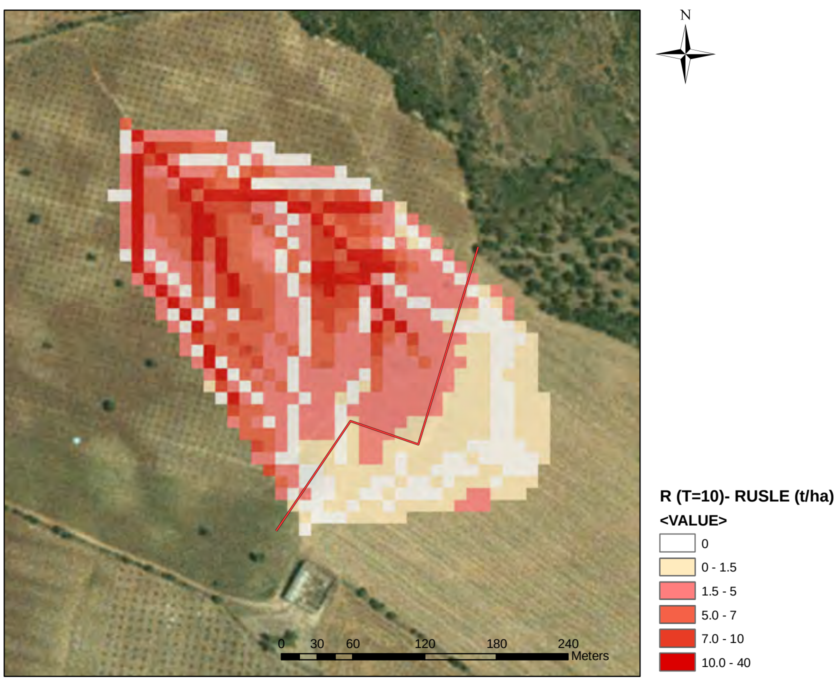
1.5 - 5
5.0 - 7
7.0 - 10
10.0 - 30


N
0 30 60 120 180 240
Meters
R (T=10)- RUSLE (t/ha)
<VALUE>
0
0 - 1.5
1.5 - 5
5.0 - 7
7.0 - 10
10.0 - 40

1