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Water erosion in olive orchards in Andalusia (Southern Spain): a review.

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Abstract

Olive is the most extended crop in Andalusia, the Southern region of Spain, with 1.48 Mha (Consejería de Agricultura y Pesca, 2003), covering 17% of Andalusian lands. The widespread extension of this crop makes any environmental problem related to olive cultivation a serious environmental issue, especially in catchments where olive is the primary crop. Despite the expansion of irrigation during the last decade, most olive production remains under rain fed conditions, on sloping land and at low tree density. Low density, sparse tree canopies maintained by pruning, and weed control by frequent tillage are the main agronomic strategies used historically to ensure the stability of production of rain fed orchards and their survival during droughts. However, the steep slopes and the reduced ground cover can cause water erosion, which is an important problem in most olive growing areas. Despite the concern and awareness about this problem, uncertainty about soil losses in olive orchards in Andalusia remains high. This paper reviews the information available on soil losses from published or on-going experiments, and the predictions from erosion models in the olive orchards of Andalusia. The paper analyses the uncertainties associated with the various estimations of soil losses, and suggests key issues for future research.

The widespread concern about the magnitude of water erosion in olive areas in Andalusia, has lead to statements where an average soil loss rate for the olive growing

areas in Andalusia of 80 t ha^{-1} yr^{-1} is commonly mentioned (e.g. Pastor et al., 1998). The source of this figure is found in López-Cuervo (1990) who made an estimation of soil losses based on USLE (Wischmeier et al., 1978) calibrated from low resolution topographical, soil and crop data (1:50.000 scale or higher). Despite Lopez Cuervo´s remarks that this large-scale estimation does not consider deposition within the catchments and that this deposition could be significant, 80 t ha^{-1} yr^{-1} has become the conventionally accepted average soil loss rate in olive areas in Andalusia. The whole story of how such a figure has become conventional wisdom is not very different than that pointed out by Boardman (1998) about the 17 t ha^{-1} yr^{-1} average soil loss rate for Europe, a figure that actually came from a 0.11 ha plot of sloping Belgian farmland.

A closer look to the available experimental data of soil loss in olive orchards in Andalusia showed that this information is limited to a handful of plot experiments. Francia *et al.* (2000) measured over one season, soil losses of 42.5, 3.4 and 10.1 t ha^{-1} for no tillage, cover crop strips between tree rows sown in fall and chemically killed in early spring, and conventional tillage plots respectively (one replication each on a 30% slope). Gómez y col. (2004) measured average soil losses of 8.5, 4.0 and 1.2 t ha^{-1} yr^{-1} over a three year period, for no tillage with soil kept bare with herbicide, cover crop strips between tree rows sown in fall and chemically killed in early spring, and conventional tillage plots respectively (three replications for each treatment on an average slope of 13%). Arroyo (2004) measured during a two year period average soil losses of 25.1, 10.3 and 7.4 t ha^{-1} yr^{-1} for no tillage with soil kept bare with herbicide, strips of barley sown as cover crop between tree rows sown in fall and chemically killed in early spring, strips of natural vegetation grown as cover crop between tree rows during fall and winter chemically killed in early spring respectively (one replication each, 30% slope). In an on-going experiment at two different locations Gómez et al. (unpublished) have measured the first year, losses of 0.5 and 50 t ha^{-1} yr^{-1} for strips of cover crop between tree rows sown in fall and chemically killed in early spring and conventional tilled plots respectively (one replication each, 13% slope), and 0.2 and 3.0 t ha^{-1} $yr^{-1}$for strips of cover crop sown in fall and chemically killed in early spring between tree rows and conventional tilled plots respectively in a different location (one replication each, 4% slope).

Although in a few cases the measured losses from experimental plots have been quite high, they have been much less than the conventional value of 80 t ha^{-1} yr^{-1}, even when these results were extrapolated using the L factor of RUSLE (Renard et al. 1997) to the slope length characteristic of the zone where the plot experiments were conducted. These results do not preclude the existence of areas of intense erosion in olive orchards, evidence of which can be found in the region and has been described by different authors, for example Laguna (1989) based on Cs-137 activity. However, these results from the experimental plots suggest that soil losses may be significantly lower that previously believed, especially in areas where the farmer allows a cover crop or natural vegetation to grow between the tree rows during winter and fall. This is because these experimental results indicate that a cover crop has a large effect in reducing soil loss when compared to conventional tillage or no tillage with soil kept bare with herbicide. In addition, cover crops reduce nutrient (Gómez, unpublished) and runoff losses (Gómez et al. 2004). This critical role of cover crop in orchards have been demonstrated by Raglionne et al. (1999) in Italy, who measured soil losses of 0.35 t $ha^{-1}yr^{-1}$, and Kosmas et al. (1996) in Greece, with 0.03 t $ha^{-1}yr^{-1}$. Field surveys based on erosion symptoms in sloping areas suggest that soil losses are moderate when for a soil management that promotes ground cover is used (Millgroom et al., 2005). The main obstacle for the increase in the adoption of cover crop in olive orchards is the risk of loosing production due to competition for soil water with the tree. That is why the cover crop has to be either killed by herbicide or mowed in early spring. Unfortunately, the optimal killing date varies from year to year due to weather fluctuations. Field experiments and numerical simulations (Castro, 2004) have demonstrated that there is an inherent risk of yield reduction associated with the use of cover crops in rain fed orchards, as 1-2 week delay in removing the cover crop, could represent significant yield losses in dry, warm springs. Several on-going projects are aimed to precisely define that optimum killing date and the associated risk of yield loss for a wide range of olive orchard characteristics based on simulation models.

The influence of soil management on soil loss in olive orchards in Andalusia have been estimated using RUSLE (Renard et al., 1997) calibrated for the different soil management methods used in the region (Gómez et al. 2002). This model analyses also indicates a large influence of soil management in reducing soil loss, predicting that soil losses can be kept to a minimum in some situations by the use of a cover crop. These modelling results are consistent with the experimental results previously commented, and suggest that some previous USLE-based large scale estimations of soil erosion: López Cuervo (1990); Moreira-Madueño (1991); Kok et al. (1995); may have overestimated soil losses due to the use of a single homogeneous value for the C factor for describing the effect of soil management, all using a C value corresponding to intense tillage, as compared to a more accurate calibration taking into account the actual soil management. Additionally, neither Gómez et al. (2002), Kok et al. (1995), Moreira-Madueño (1991), or López-Cuervo (1990) took into account the protective role of stone cover. Stony soils are not uncommon in the region, and surface cover by stone in that can be as large as 70% in some olive orchards (Alcántara, personal communication). When stone soil cover has been considered in the calibration of RUSLE in sloping orchards nearby Cordoba it has resulted in a further reduction in soil loss predictions, (around 75%; Alcantara, unpublished) as compared to previous estimations that ignored stone cover. The apparent bias towards large soil loss in the large scale estimations previously described, suggests the need for introducing new approaches into the calibration of models used in large scale estimation, using remote sensing and linking ground cover and soil management, as well as improved erosion prediction technology. A good example of this approach can be found in the PESERA model (Kirkby et al., 2003). In addition to its improved technology for predicting erosion losses compared to RUSLE (Kirkby et al., 2003), the PESERA model uses land cover acquired trough GIS images 1 Km grid resolution as a key parameter. The PESERA GRID model (Jones et al., 2004) predictions for olive growing areas in Andalusia are significantly lower than the previously large scale USLE based estimations, especially in the areas where soil management allows vegetation to grow between the tree rows. Whether this is mostly a result of the improved erosion assessment technology, or is due to the use of vegetation cover as a key parameter in the model and its calibration, is not clear. Nevertheless, these results suggest that improved prediction technology and the use of a key element of a vegetative ground cover in model calibration may significantly change our perception about the intensity and extension of water erosion in olive areas.

Reliable predictions of the amount of removed soil deposited within the catchment before reaching the water courses are critical for accurate estimations of soil losses and its on-site and off-site effects (Trimble and Crosson, 2000; Nearing et al., 2000). We have found quite limited estimations of the fraction of soil lost in hillslopes that actually reach water courses in olive areas. Ayala (2004) calculated for a 10 ha olive farm forming a small watershed soil loss of 6.6 t ha^{-1} yr^{-1} using USPED (Mitas and Mitasova, 1998) and high resolution DEM (1.5-m grid size), and a sediment delivery ratio around 9%. He also noted large areas of sediment deposition within the modelled catchment in a field survey. For the same farm, Ayala (2004) using WATEM (Verstraeten et al., 2002) calculated a soil loss of 1.7 t ha^{-1} $yr^{-1}$and a sediment delivery ratio around 6%. Schoorl and Vedkamp (2001) using the LAPSUS model (Schoorl et al., 2002) predicted for a mixed landscape with a large extension of olive orchards sediment delivery ratios of 75%, and 4.0 t ha^{-1} yr^{-1}soil loss for olive orchards. Aguilera (2004) using AGNPS (Young et al., 1989) predicted for a small 3.9 ha olive covered watershed soil losses of 2.5 t ha^{-1} $yr^{-1}$for the most erosive soil management simulated, bare soil all year round by use of herbicide. In an on-going study over a 30.000 ha olive growing area Lorite y col. (unpublished) have calculated average soil losses of 6.3 t ha^{-1} yr^{-1} with a sediment delivery ratio of 40%. Unfortunately, none of these soil loss ratios or sediment delivery ratios have been validated against experimental data of sediment loss, or estimations of soil redistribution using sediment tracers. However, all these models have predicted soil losses significantly lower than many large scale estimations, a low sediment delivery ratio indicating that most of the sediment lost is deposited before reaching a water course. Some on-going experiments by our group may provide validation for Ayala (2004) and Aguilar (2004) soil loss predictions in the coming years.

We believe that there is a need for increasing the number of field experiments measuring soil loss in olive orchards if we want to reduce the uncertainty in erosion prediction in olive areas using the present or an improved erosion prediction technology. This is true for plot scale, but even more critical at the catchment scale. There is also a need for field studies aimed at understanding and quantifying sediment redistribution within olive groves. The results from plot experiment, model analysis at watershed scale and the large scale PESERA assessment suggests that soil loss in olive areas might be significantly lower that conventionally accepted. This does not mean that areas of accelerated erosion do no exist (e.g. Laguna, 1989; Gómez et al. 2002), rather than these are circumscribed to some specific areas, and at probably related to specific soil management techniques. Reliable estimations of the degree and spatial distribution of soil losses at farm scale unit are going to be of critical importance if the current Common Agricultural Policy reform, linking subsidies to specific environmental regulations, succeeds. Incorporating actual soil management and high resolution ground cover information in the calibration of erosion models will be critical to obtain reliable estimations. Soil management information might be achieved by cooperative research with Cooperatives or farmer associations or with Government Agencies, and some examples are been implemented (Lorite personal communication), while improved ground cover information could be achieved through the use multispectral remote sensing imagery analyzed with physically based models (Zarco et al., 2005).

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