Nutrient losses from a vineyard soil in Northeastern Spain caused by an extraordinary rainfall event

M.C. Ramos*, J.A. Martínez-Casasnovas

University of Lleida, Alcalde Rovira Roure 191, E-25198 Lleida, Spain

Received 22 March 2002; accepted 28 March 2003

Abstract

Vineyards are one of the lands that incur the highest soil losses in Mediterranean environments. Most of the studies that report about this problem only focus on soil losses and few investigations have addressed the nutrient losses associated with erosion processes during the storms. The present research evaluates the loss of nitrogen, phosphorus and potassium in vineyard soils located in a Mediterranean area (NE Spain), after an extreme rainfall event recorded on 10 June 2000. The total rainfall of this event was 215 mm, 205 mm of which fell in 2 h 15 min. The maximum intensity in 30-min periods reached 170 mm h$^{-1}$. This rainfall produced a large amount of sediments both inside and outside the plots, with the consequent soil mobilisation and loss of nutrients. The estimate of soil loss was based on the subtraction of two very accurate digital elevation models (DEMs) of different dates in GIS, and measures of the nutrient content of sediment collected in the plot. Soil loss in the study plot reached 207 mg ha$^{-1}$. Most sediment was produced by concentrated surface runoff. Nutrient losses amounted as 108.5 kg ha$^{-1}$ of N, 108.6 kg ha$^{-1}$ of P and 35.6 kg ha$^{-1}$ of K. The proposed method allowed mapping the sediment contribution and deposition areas and the distribution of the nutrient load and losses within the plot.

© 2003 Elsevier Science B.V. All rights reserved.

Keywords: Extreme event; Erosivity; Soil erosion; Nutrients; DEM (digital elevation model); Vineyard; Mediterranean climate

1. Introduction

The Mediterranean climate is characterised by a complex pattern of spatial and seasonal variability, with wide and unpredictable rainfall fluctuations from year to
Extreme rainfall events of high intensity are frequent phenomena in this region (Llasat and Puigcerver, 1992, 1994; López-Bermúdez and Romero-Díaz, 1993; Ramos and Porta, 1994), which are disruptive for natural and human systems (IPCC, 1995).

Imeson (1990) pointed out that the main climatic characteristics affecting the vulnerability of the Mediterranean region to erosion are the high intensity rainfalls that occur after a very dry summer and the high climatic fluctuation in short and long term, especially in rainfall quantity. Other factors, such as an abundance of unconsolidated parent materials (marls, limestones and sandstones) (Poesen and Hooke, 1997; Martínez-Casasnovas, 1998), rainfed crops that partially cover the soil (vineyards, almond and olive trees), abandonment of land and/or elimination of soil conservation measures (Cerdà, 1994; Chisci, 1994; Porta et al., 1994; Pastor and Castro, 1995; Martínez-Casasnovas, 1998; Usón, 1998), also constitute favourable conditions for soil erosion by water accelerating the erosion processes.

Some evaluations carried out in the Mediterranean European region, representing different landscapes and different land uses (eucalyptus, olive, shrubs, vines, wheat–fallow), point out that vineyards are the lands that incur the highest runoff and soil losses (ranging between 0.67 and 4.6 mg ha\(^{-1}\) year\(^{-1}\)) (Kosmas et al., 1997). Assessment soil losses carried out in vineyards in Napa Valley (California) with rainfall simulation recorded soil losses up to 176 kg ha\(^{-1}\) for 40 min of 60 mm h\(^{-1}\) rainfall. Other authors give higher figures for other specific sites: 47–70 Mg ha\(^{-1}\) year\(^{-1}\) in NW Italy (Tropeano, 1983), 35 Mg ha\(^{-1}\) year\(^{-1}\) in the Mid Aisne region (France) (Wicherek, 1991), and 22 Mg ha\(^{-1}\) year\(^{-1}\) in the Penedès–Anoia region (NE Spain) (Usón, 1998). Even higher soil losses have been associated with extreme rainfall events: 34 Mg ha\(^{-1}\) in an extreme rainfall in the SE France (Wainwright, 1996), or 18–22 Mg ha\(^{-1}\) due to rill erosion measured at plot scale between September and November (Ramos and Porta, 1997). Most of these studies only focus on soil losses and less work has been done to investigate nutrient losses associated to soil erosion during the storms. Some studies have examined the fluxes of dissolved nutrients or associated with suspended sediments in small plots (Schlesinger et al., 2000) or in small watersheds dominated by cropland, grassland, shrubland and forest (e.g. Romkens et al., 1973; DeBano and Conrad, 1976; Burwell et al., 1977; Owens et al., 1983; Dorioz and Ferhi, 1993; Hedin et al., 1995; Pionke et al., 1996; Correll et al., 1999), or have carried out experiments with rainfall simulators (e.g. Barisas et al., 1978; Schlesinger et al., 1999; Eghball and Gilley, 1999). These studies have shown a great variability in nutrient losses related to differences in land use and management practices. Most of the total suspended sediment is lost during unusually large and intense storm events. On this respect, Steegen et al. (2001) also pointed out that the occurrence of important events is the major factor explaining differences in sediment and nutrients export between two catchments. Although some studies make reference to nutrient losses in time periods that include some extreme events (e.g. Douglas et al., 1998; Steegen et al., 2001), very few works quantify the losses associated with a particular event.

The present research evaluates the loss of nitrogen, phosphorus and potassium in vineyard soils located in the Mediterranean area, after the extreme rainfall event recorded on 10 June 2000 in NE Spain. The most common cropping practice in vineyards of this...
area is to maintain the soil bare with continuous tillage, which favours soil and nutrient losses. The method used to assess soil loss was based on the subtraction of two very accurate digital elevation models (DEMs) formulated for different dates in a GIS environment, coupled to nutrient loss from sediment collected in a vineyard plot. The proposed method also allowed mapping the sediment contribution and deposition areas within the plot.

2. Material and methods

2.1. Study area

The study area is located in the Alt Penedès–Anoia region (Catalonia, Spain) (Fig. 1). This area has a Mediterranean climate, with a mean annual temperature of 15 °C (Elías Castillo and Ruiz Beltrán, 1979) and an annual rainfall of 550 mm (Ramos and Porta,
1993). The rainfall concentrates mainly in two periods: September to November and April to June. One of the main characteristics of the rainfall is its high intensity, especially for those storms recorded in autumn (Ramos and Porta, 1994).

2.2. Field plot characteristics

In the area, most soil profiles have been truncated by hydric erosion and underlying horizons are now at the surface. The present case study makes reference to a mechanised vineyard plot. The vineyard plot object of the present study has an area of 21,200 m² (dimensions of the plot: 175 m long and 125 m width) (Fig. 2). The plot was levelled 10 years ago. The upper part of the plot was cut (up to 2 m) and some parts at the bottom were filled with material taken from other parts. However, the topsoil layer was preserved and restored at the top position after the levelling. This plot is limited all around by a road, so no runoff is received in the plot from outside. The average slope of the plot is 8.9%. After several years, composted cattle manure has been added in alternated rows in addition to the usual fertilisation.

The plantation consists of trained vines, with a 1.3 × 3.1 m pattern. The vine rows are perpendicular to the maximum slope gradient. Every eight rows there is a hillside ditch or

Fig. 2. Plot characteristics and location of the sediment collectors along the slope. The figure also shows the altitude differences in the plot computed from the high resolution DEMs from before and after the 10 June 2000 rainfall event used to calculate soil and nutrient losses.
broadbase terrace (named locally “rasa”), which functions to intercept surface runoff and convey it out of the plot (Porta et al., 1994). Part of the sediments generated above these ditches is also deposited in them (Fig. 2).

Vineyards are maintained with the soils bare for most of the year and during the growing season, plant cover is up to 50%. At the time of the storm the crop was in the period between the bloom and the veraison, which usually starts at the end of June. The leaf area index at that moment, estimated using PATTER model (Mulligan, 1996), was about 2.2 m² leaf/m² ground.

2.3. Soil characteristics

Soils are highly calcareous. According to Keys of Soil Taxonomy (Soil Survey Staff, 1998), the soils of the plot are classified as Typic Xerorthents (Martínez-Casasnovas, 1998). Some specific soil properties of the surface soil (0–20 cm): particle size distribution (USDA system), organic matter (o.m.), calcium carbonate, texture, pH and electric conductivity (E.C.1:5), evaluated according to the methods of Porta et al. (1986), are given in Table 1.

2.4. Characteristics of the extreme rainfall event

The extreme event was recorded on 10 June 2000 using a tipping bucket rain gauge connected to a data logger, which registered data every 1 min. This rain gauge was situated 500 m from the vineyard plot where the study was carried out. From the recorded data, the depth, duration, average and maximum intensity in a 30-min period were evaluated. The erosivity of this event was calculated by the $R(KE \times I_{30})$ erosivity index proposed by Wischmeier and Smith (1978), where KE is the kinetic energy of the rainfall and $I_{30}$ is the maximum intensity in a 30-min period. Kinetic energy was computed from the intensity values, using the relationship obtained for this area (Ramos, 1999). Total rainfall was compared to the rainfalls corresponding to different return periods that have been evaluated from historical records of the Spanish Instituto Nacional de Meteorología (INM), located in the study area: Esparreguera, Gelida, Piera and Sant Sadurní d’Anoia. The rainfalls recorded in the area between the two dates considered for the analysis of soil losses (17 March–20 June) were 66 mm, distributed in eight events. Only three events produced runoff (rainfalls of 23, 12,4

Table 1
Soil characteristics of the 0–20 cm surface soil of the plot evaluated at the four sample points (see location of sample points in Fig. 2)

<table>
<thead>
<tr>
<th>Sample point</th>
<th>o.m. (%)</th>
<th>pH</th>
<th>CaCO₃ (eq/100)</th>
<th>E.C. (1:5) (dS/m)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Sand (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.73</td>
<td>8.0</td>
<td>37.8</td>
<td>0.51</td>
<td>42.4</td>
<td>9.1</td>
<td>48.6</td>
</tr>
<tr>
<td>II</td>
<td>0.59</td>
<td>8.1</td>
<td>38.7</td>
<td>0.49</td>
<td>42.1</td>
<td>9.6</td>
<td>48.2</td>
</tr>
<tr>
<td>III</td>
<td>0.36</td>
<td>8.6</td>
<td>38.7</td>
<td>0.28</td>
<td>45.0</td>
<td>12.0</td>
<td>43.0</td>
</tr>
<tr>
<td>IV</td>
<td>1.05</td>
<td>8.4</td>
<td>20.3</td>
<td>0.15</td>
<td>47.8</td>
<td>8.0</td>
<td>54.8</td>
</tr>
</tbody>
</table>
and 13.2 mm) which represented less that 10% of the rainfall. The maximum intensity of the rainfalls was 11.5 mm h\(^{-1}\).

2.5. Evaluation of soil losses during the extreme event

An estimate of sediment production by the extreme rainfall event was based on the subtraction of two high resolution digital elevation models (DEMs), the first one from before (17 March 2000) and the second one 10 days after the storm (20 June 2000) (when it was possible to walk on the plot). Both DEMs were generated from very detailed topographic surveys. The surveys were carried out by the same team using a TOPCON GTS-303\(^{\text{®}}\) total station. The number of points registered for each survey was 237 (17 March 2000) and 288 (20 June 2000). Those figures are greater than or equal to the minimum number of points recommended for very detailed topographic surveys in the case of undulating or complex relief (between 150 and 250 points for scale 1:200). Both surveys were made without interference of atmospheric conditions. Special attention was paid to the zones within the plot were ephemeral gullies were observed during the latest survey, collecting a highest density of height points in those zones to get a better terrain representation. Ephemeral gully network lines were also digitised and entered as hard break lines to construct the 20 June DEM. The construction of the base DEMs were made with TCP (Autodesk\(^{\text{®}}\)) software. From the contours and break lines, the DEMs were generated by means of a random triangulation using all the points following Delaunay method (Burrough and McDonnell, 1998), using ARC/INFO Version 7.1.2 (ESRI\(^{\text{®}}\)). Points along contours were considered as mass points and the boundary of the plot and the drainage network within the plot were used as break lines. The resulting triangulated irregular networks (TINs) were used to compute both grids by means of spatial interpolation. Cells were given the height value found at the intersection between the perpendicular at the centre of each cell and the corresponding triangle in that spatial location. The spatial resolution given to the DEMs was 0.2 m.

An average value of 1250 ± 90 kg m\(^{-3}\), computed from bulk density measurements carried out in the study plot, was considered as the bulk density value of the topsoil layer in order to estimate the weight of the lost soil and that sedimented.

2.6. Sediment collection and analysis

Two replicate collections of sediments were collected in each of four positions distributed along the slope of the plot (Fig. 2), with two replications in each of them. A common practice in this farm is to add, organic compost every 3 years in alternate rows at a rate of 40 mg ha\(^{-1}\) (dry wet basis). At each sample point one collector was located in the row with added compost and another in the row without compost. Each collector consisted in a Gerlach box, 50-cm width, which allowed separation of the sediment and the runoff samples. Total phosphorus (Olsen and Sommers, 1982), total nitrogen (Bremner and Mulvaney, 1982) and potassium (Knudsen et al., 1982) were analysed in the sediments collected at each point. In addition dissolved phosphorus (American Public Health Association (APHA), 1995) was also evaluated in runoff water.
3. Results

The total rainfall recorded during the extreme event occurred on 10 June 2000, in the rain gauge station located in the field was 215 mm, 205 mm of which fell in 2 h 15 min. This 24-h rainfall has a return period of 105 years. However, it occurred in a shorter period of time, which confers it an extraordinary character. The average intensity of the downpour was 91.8 mm h\(^{-1}\), with maximum intensity in 30-min periods up to 170 mm h\(^{-1}\). The rainfall erosivity of this storm, evaluated by the product of kinetic energy and the maximum intensity in 30 min, reached a value of 11,756 MJ ha\(^{-1}\) mm h\(^{-1}\). This value is 10 times greater than the annual \(R\) value for this area (Ramos and Porta, 1994), which shows the very high erosive potentiality of this storm. The water balance computed using a hydrological model (Pla, 1997) for this event showed that only about 20% of the water infiltrated (Ramos et al., 2002). The rest of the rainwater was lost as surface runoff.

3.1. Soil characteristics

Table 1 shows some characteristics (organic matter (o.m.), pH, calcium carbonate, electric conductivity (E.C.) and texture) of the surface soil horizons, collected before the event at the points were the sediment collectors were installed. The most notable characteristics are the low organic matter content, ranging between 0.36% and 1.05%, and the relatively high silt content, averaging about 45% in the plot. Some authors state that silt content is the main factor responsible for seal formation and increasing runoff (Pla, 1986; Norton, 1987).

3.2. Soil losses

The subtraction of the two analysed raster DEMs yielded a new grid with the altitude differences (Fig. 2). This grid clearly shows areas that suffered soil loss (negative difference values) and areas where sedimentation occurred (positive difference values). The sum of the negative values represents the amount of soil that was detached and mobilised in the plot by the generated surface runoff. That was 828 \(\pm\) 13 m\(^3\), equivalent to 1035 \(\pm\) 28 mg (487 \(\pm\) 13 Mg ha\(^{-1}\)). Some of those materials, 57% (476 \(\pm\) 17 m\(^3\)), equivalent to 595 \(\pm\) 21 mg (280 \(\pm\) 10 Mg ha\(^{-1}\)) were deposited in other areas within the same plot. The sum of both figures, negative and positive values, gives the net amount of soil loss or soil deposition. In the present case, the balance was negative, with a net total of 352 \(\pm\) 36 m\(^3\), or 207 \(\pm\) 21 Mg ha\(^{-1}\). The majority of those sediments were produced by concentrated surface runoff. As it can be observed in Fig. 2, soil losses were very high in some points of the plot. Especially along the flow concentration lines, up to 0.5 m of the topsoil were moved producing rills and ephemeral gullies. However, the existence of the drainage terraces, helped not only in the elimination of the excess of water from the field, but to sediment some of the eroded soil, which filled up the terraces.

The other rainfalls recorded in the area between the two considered dates (17 March–20 June 2000) produced very low soil loss (0.78 mg ha\(^{-1}\) for all rainfalls) in comparison with those obtained during this extraordinary event, which is much lesser than the error of the method used in this analysis.
3.3. Nutrient losses

Table 2 shows the chemical concentrations in the sediments and water runoff recorded after the storm at the eight collectors located along the slope. Because of the application of the organic compost in alternated rows, the N, P and K levels in four of the eight collectors were quite different than the other four. The composted and non-composted areas were distributed uniformly along the slope. On the other hand, the irregularities of the slope make that in some points there is flow accumulation and higher runoff than in others. But considering the total soil sediment and the nutrient concentrations at each point there are no significant differences related to location. To evaluate the total nutrient losses of the plot, the average value of the eight samples was considered. Total nitrogen in sediments ranged from 310 to 897 mg kg\(^{-1}\). Total phosphorus ranged from 414 to 636 mg kg\(^{-1}\) and potassium ranged from 136 to 212 mg kg\(^{-1}\).

Collectors 1, 2, 7 and 8 (points I and IV) were located in a line of surface runoff concentration, while collectors 3, 4, 5 and 6 (points II and III) were out of the line of flow concentration. However, no significant differences were found in nutrient concentrations with respect to location. Due to the management practices carried out in the plot, with the addition of composted cattle manure, high differences were observed in the different collectors. The highest values were observed in positions II and IV for the three nutrients, while in those points the soil losses were lower than in the other two positions (Fig. 2). The results show the difficulty of analyzing locally soil losses and nutrient losses. Because of that, we used the information recorded in the eight collectors to estimate the total average nutrient losses in the plot.

Taking into account the soil loss and sedimentation areas, we estimated the distribution of the nutrient load and losses associated with the mobilised soil. There are areas with losses higher than 300 g m\(^{-2}\) of N, 250 g m\(^{-2}\) of P and 80 mg m\(^{-2}\) of K, and areas of sedimentation with loads higher than 400 g m\(^{-2}\) of N, 3000 g m\(^{-2}\) of P and 110 mg m\(^{-2}\) of K. Taking into account the average soil losses recorded in the plot, the nutrient losses

<table>
<thead>
<tr>
<th>Sample point</th>
<th>Collector</th>
<th>Nitrogen sediment (mg kg(^{-1}))</th>
<th>Phosphorus</th>
<th>Potassium sediment (mg kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sediment (mg kg(^{-1}))</td>
<td>Runoff water (mg l(^{-1}))</td>
<td>Sediment (mg kg(^{-1}))</td>
</tr>
<tr>
<td>I</td>
<td>1</td>
<td>350</td>
<td>423</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>560</td>
<td>613</td>
<td>0.78</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
<td>500</td>
<td>402</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>896</td>
<td>636</td>
<td>0.72</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
<td>310</td>
<td>414</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>530</td>
<td>639</td>
<td>0.64</td>
</tr>
<tr>
<td>IV</td>
<td>7</td>
<td>320</td>
<td>441</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>730</td>
<td>640</td>
<td>0.76</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>524 ± 206</td>
<td>515 ± 115</td>
<td>0.63 ± 0.12</td>
</tr>
</tbody>
</table>

Nitrogen and potassium in runoff water were below the detection limits.
associated with soil loss were 108.5 kg ha$^{-1}$ of N, 107.6 kg ha$^{-1}$ of P and 35.6 kg ha$^{-1}$ of K.

Mean dissolved phosphorus in runoff water was 0.63 mg l$^{-1}$, with little variation among sampling points along the plot. Taking into account that only 20% of the rainfall fell during the event infiltrated, the additional phosphorus losses by runoff was about 1.09 mg ha$^{-1}$, which make a total phosphorus loss of 108.6 kg ha$^{-1}$. Soluble forms of nitrogen in runoff water were below the detection limits.

4. Discussion and conclusions

The rainfall event of 10 June 2000 had an extraordinary character, not only because of the total depth of rainfall but also because it occurred in a short period of time. The rainfall erosivity was 10 times higher than the annual erosivity of the rainfalls recorded in the area. This storm mobilised 487 mg ha$^{-1}$ of soil, and the plot lost 207 mg ha$^{-1}$. This value is much higher than those recorded in extreme rainfall events found in the literature and even higher than the annual soil losses recorded in other Mediterranean regions (Tropeano, 1983; Wicherek, 1991; Wainwright, 1996). The method used to quantify soil losses allowed the mapping of sediment deposition areas as well as areas where soil was lost. The use of sediment collectors for these purposes would have given erroneous information; the total amount of soil that was mobilised could have been estimated but not the amount that sedimented. For that reason, the methodology used to quantify and to map soil losses, based on the subtraction of very high resolution DEMs (Martínez-Casasnovas et al., 2002), could be considered as very suitable in the cases of occurrence of high intensity rainfalls, which produce high erosion rates.

Total nitrogen, phosphorous and potassium losses associated with the rainfall event were 108.5 kg ha$^{-1}$ of N, 108.6 kg ha$^{-1}$ of P and 35.6 kg ha$^{-1}$ of K, but in certain areas inside the plot there were losses higher than 3000 kg ha$^{-1}$ of N, 2500 kg ha$^{-1}$ of P and 800 kg ha$^{-1}$ of K, and areas of sedimentation with loads higher than 4000 kg ha$^{-1}$ of N, 2000 kg ha$^{-1}$ of P and 1100 kg ha$^{-1}$ of K. These figures are much higher than those corresponding to the annual losses obtained in the same area with a total annual rainfall of 937 mm and storms with average rainfall intensities not higher than 31 mm h$^{-1}$ (24.4, 0.98 and 6.4 kg ha$^{-1}$ for N, P and K, respectively) (Usón, 1998). The rainfall of June 2000 has a recurrence period of 105 years, which is not comparable with any other study related to nutrient losses due to extreme rainfall events. Steegen et al. (2001) gave information about phosphorus losses in two catchments in which some extreme events were recorded, but the highest occurrence period was 10 years, with a register of only 12.4 mm in 49 min. The figures are also higher than those reported by Douglas et al. (1998), who showed N annual losses ranging from 20 to 100 kg ha$^{-1}$ year$^{-1}$ and P losses ranging from 8 to 48 kg ha$^{-1}$ year$^{-1}$ in plots under continuous fallow, in contrast to N losses of 5–70 kg ha$^{-1}$ year$^{-1}$ and P losses of 2–28 kg ha$^{-1}$ year$^{-1}$ in winter wheat. These studies make reference to nutrient losses in time periods that include some extreme events. Much lower figures were observed by Debano and Conrad (1976) in undisturbed chaparral on sites of shallow slopes in California (N losses of 15.1 kg ha$^{-1}$ year$^{-1}$ and P losses of 3.5 kg ha$^{-1}$ year$^{-1}$ in the particulate form), or those found by Schlesinger et al. (2000) in desert...
shrubland (0.33 kg ha\(^{-1}\) year\(^{-1}\)) and grasslands (0.15 kg ha\(^{-1}\) year\(^{-1}\)), areas in which the coefficient runoff was always less than 25%.

According to the information provided by the farmers and the content of N, P and K in the added compost, the annual nutrient applications were 870 kg ha\(^{-1}\) year\(^{-1}\) of N, 180 kg ha\(^{-1}\) year\(^{-1}\) of P and 350 kg ha\(^{-1}\) year\(^{-1}\) of K. Thus the nutrient losses during the storms represent 12.5%, 60.5% and 10.2% of the annual inputs of N, P and K, respectively. These percentages are less for N and higher for P than those reported by Mihara (2001), who investigated the losses of nitrogen and phosphorous produced by a typhoon with a rainfall of 143.5 mm in plots with rates of fertilisation ranging from 100 to 500 kg ha\(^{-1}\) year\(^{-1}\) of N and 32 to 150 kg ha\(^{-1}\) year\(^{-1}\) of P. The losses in that case reached values ranging between 20% and 49% of the applied N and between 35% and 45% of the applied P.

The management practices followed in this plot could be considered representative of those applied in new cultivation systems after mechanisation of the fields. The area is dissected by a network of gullies which drains to the Anoia and Llobregat rivers, which receive the nutrients removed from fields. This event not only produced important losses for farmers, and an important non-point source pollution of the river that receive runoff of the area.

Acknowledgements

This work as part of the AMB98-0481 Project, 1998–2001, was developed with funding from the the Comision Interministerial de Ciencia y Tecnologia, (CICYT), Progama Nacional de Medio Ambiente. The authors also thank M. Ribes, A. Llongarriu and D. Farré for their assistance during the topographical surveys.

References


IPCC, 1995. IPCC second assessment synthesis of scientific technical information relevant to interpreting article 2 of the UN Framework Convention on Climate Change, the summary for policy makers. WHO.


Pla, I., 1986. A routine laboratory index to predict the effect of soil sealing on soil and water conservation.


