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Water Erosion from Agricultural Land Under Atlantic Climate

Montserrat Valcárcel[1], Antonio Paz González[2], Jorge Dafonte[1],
José Manuel Mirás-Avalos[2], Jorge Paz-Ferreiro[3],
Ildegardis Bertol[4] and Eva Vidal Vázquez[2]
[1]Escuela Politécnica Superior de Lugo. University of Santiago de Compostela (USC)
[2]Facultad de Ciencias. University of Corunna (UDC)
[3]Centro de Investigaciones Agrarias de Mabegondo (CIAM). Corunna
[4]CAV. Universidade do Estado de Santa Catarina (UNESC). Lages, SC
[1,2,3]Spain
[4]Brazil

1. Introduction

1.1 Background

Types and rates of water erosion depend on the following main factors: climate, soil, topography, land cover and use. Agricultural land use removes the vegetative cover resulting in accelerated wind and water erosion. Water flow and its paths are central to the study of water erosion (e.g. Flanagan, 2002). Erosion caused by water is best examined on the basis of the spatial context in which erosion takes place (e.g. Govers, 1987; Ludwig et al., 1996; Souchere et al., 1998). The smallest and simplest catchment can be defined by the area of overland flow adjacent to a single channel. Within a catchment, the major types of water erosion are: interril, rill, ephemeral gully and permanent, incised gully. Interril and rill erosion occur on hillslopes driven by overland flow (e.g. Toy et al., 2002). Rill erosion progresses to gully erosion when deeply incised channels are produced. Ephemeral gullies are periodic refilled by farming operations, whereas permanent incised gullies, which are wider and deeper, are not filled with normal framing operations (e.g. Toy et al., 2002; Flanagan, 2002).

In many areas of Northwest Europe, concentrated flow (rill and gully) erosion of agricultural land are particularly widespread, and this in spite of the low rainfall intensity characterizing Atlantic climate and a moderate topography. From 1980´s onwards, erosion studies have been a matter of interest in several European areas with loamy soils, frequently underlain by loess and/or calcareous parent material. This was the case in Pays the Caux and other regions in North and Northwest France (e.g. Boiffin et al., 1988; Auzet et al., 1993, 2006; Ludwig et al., 1996), South Downs in England (e.g. Fullen and Red, 1987; Boardman, 1990), Central Belgium (e.g. Govers, 1987, 1991; Poesen and Govers, 1990; Vandaele and Poesen, 1995) and the Province of Limburg in the Netherlands (e.g. Kwaad, 1991). Concentrated flow erosion was also described in other European regions with different climate, agricultural systems and soil types, for example in the Scandinavian countries (e.g. Uhlen, 1986; Oygarden, 1996; Hasholt et al., 1997) or in the Lake Leman area (e.g. Vansteelant et al., 1997).

There is also ample information showing soil erosion is a key factor in Mediterranean regions (Solé Benet, 2006; García-Ruíz, 2010). This environment, besides high rainfall intensity, slope gradient and low organic matter content, was traditionally characterised by a land use system (e.g. vineyards, olive and almond orchards) with scarce plant cover, which has been shown to be particularly prone to soil erosion (e.g. Martínez-Casasnovas et al., 2002; Solé Benet, 2006; García-Ruíz, 2010; Nunes et al., 2011). Permanent gullies are not an exception in these regions. Nowadays, rapid changes occurred in the agricultural system (i.e. abandonment of cultivated land, technological development, expansion of wine, almond and olive) might decrease or increase soil erosion rates (García-Ruíz, 2010). However, a recent study showed that erosion rates at the plot scale are generally much lower in the Mediterranean regions as compared to other areas in Europe (Cerdan et al., 2010). This was mainly attributed to high rock fragment content, which would reduce sheet and rill erosion rates. Also the fact that much of the arable land in Atlantic areas of some European regions where erosion has been most extensively studied is located on loess soil could help to explain these results.

Rill and ephemeral gully erosion, showing patterns remembering the loess Belt area, also was typified in Iberian regions located in the transition zone between Atlantic and Mediterranean climate, for example, Southern Navarra (e.g. Casalí et al., 1999; De Santisteban et al., 2006) and Northeast Portugal (e.g. De Figueiredo et al., 1998). Rainfall erosivity in these transitional regions is generally lower than in typical Mediterranean environments, where high intensity rains also are more frequent.

1.2 Geographycal context

Regions along the Atlantic coast in Northwest and Northern Spain (Galicia, Asturias, Santander, and Basque Country) are characterized by humid, temperate climate, opposite to Mediterranean regions. Rain intensities are moderate to low, like in other Atlantic areas in Western Europe, extending from Northern Portugal to the Scandinavian countries.

The surface area of Galicia is of about 27950 km^2. According to the UNESCO aridity index, Galicia is located at the humid region of Iberian Peninsula (P/ETP > 0.75). Mean yearly rainfall is within the range of 1400–1500 mm (Martínez Cortizas et al., 1999). Rainy months are mostly from October to May. Summers are often characterized by low total rainfall depths and dryness, even though thunderstorms with high-intensity rainfall are more frequent in this season (Font-Tullot, 1983). Thus, due water deficit in summer, the rain regime of Galicia presents, to some extent, transitional features between Atlantic and Mediterranean conditions. Rain erosion rates are expected to be moderate to high in a global perspective (Díaz-Fierros and Díaz de Bustamante, 1980).

In Galicia, traditional agricultural systems were characterized by the small size of fields and by a complex system of terraces and border features separating the fields. For several centuries, thousands of kilometres of stony walls acting as terraces have been constructed at the property boundaries and they have been an important element in erosion control. In recent years properties have been redistributed in some areas, increasing the average field size and facilitating more intensive farming practices. Therefore, nowadays both traditional and intensive management systems are found side by side.

Water erosion has been investigated since 1996 on medium textured (loamy to silty loam) soils developed on parent materials belonging to the Ordenes complex and to lesser extent also on loamy to sandy loam soils developed over granite (Figure 1), in A Coruña province, Galicia (e.g. Valcárcel, 1999; Valcárcel et al., 2003; Mirás Avalos et al., 2009). Results indicated that concentrated soil erosion (rill and ephemeral gullies) also was a widespread phenomenon, so that large parts of agricultural land are affected by soil losses. Similar findings have been reported in the neighbour region of Asturias, also characterized by Atlantic climatic conditions (Menéndez-Duarte et al., 2007).

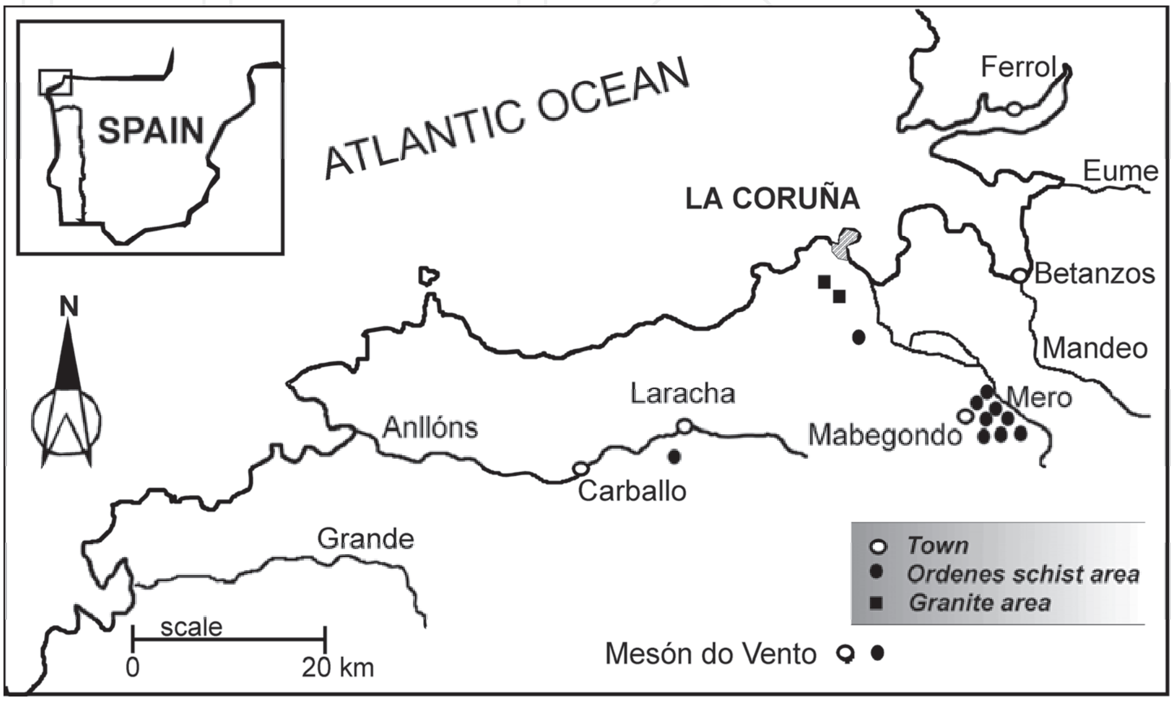


Fig. 1. Location of fields where water erosion was surveyed.

In our studied area, both Hortonian and non-Hortonian runoff might occur (Valcárcel, 1999). In general, surface runoff is related to Hortonian flow occurrence, which in turn is more frequent on agricultural fields with a seedbed prone to crusting. In these conditions, overland flow is mainly due to low infiltration rates, lower than rainfall intensity. Saturated hydraulic conductivity is not a limiting factor for infiltration, after ploughing or seedbed preparation, but it was found to decrease with increasing cumulative rainfall and crust development so that values as low as 1- 3 $mm \cdot h^{-1}$ have been measured for sedimentary crusts (González García, 1999; Taboada Castro, 2001). Values of saturated conductivity reported for crusted surfaces in medium textured soils of Northern France are of the same order of magnitude (Boiffin et al., 1988). Therefore, low infiltration rates and runoff production are controlled, by two main factors: (1) the presence of a crusted soil surface and (2) a scarce water storage capacity in microrelief depressions. Seedbeds of spring and winter cereals and even those of reseeded grasslands change under the cumulative effect of rainfall becoming land surfaces characterized by poor soil infiltration capacity and poor surface water storage.

Surveys carried out in other Atlantic regions of Europe, as before mentioned, also show that in agricultural fields from temperate-humid Atlantic climate soil losses by rill and gully erosion are much more important than those caused by laminar erosion. Crust formation and surface degradation decrease the infiltration and produce runoff. Frequently, soil management origins furrows, which favour soil incision, and therefore enhance the formation of rills and ephemeral gullies.

Notice also that during erosive events, apart from soil losses, manure and pesticide transports to surface water bodies can be produced. In fact, attention has been paid soil erosion in agricultural land not only because of concern for loss of soil fertility, but rather because of nutrients originated from the cultivated areas are an issue of concern, because they can threaten water quality.

2. Effect of soil surface changes and man-made agricultural features on runoff generation and soil erosion

The properties determining the capacity of an agricultural surface to produce runoff (i.e. soil infiltrability and surface storage) are strongly influenced by the structure of topsoil layers. Factors influencing soil surface structure and formation of soil crusts can be evaluated from field survey data (e.g. Ludwig et al., 1996; Souchere et al., 1998).

The primary mechanism leading to surface crusting was aggregate breakdown (Taboada Castro, 2001), which also produced small particles that are easy transportable by runoff water. Soil crusting consistently follows typical time and space sequences. Kinetics of soil crusting depends on factors such as soil composition (organic matter content, silt and clay content) and initial surface roughness.

To assess soil surface evolution as a function of cumulative rainfall in the soils of the Ordenes complex, field observations have been made after each important rainfall event, particularly when the soil surface was uncovered in late spring and autumn-early winter. Information recorded during this surveys included crusting stage, surface roughness, evidence of overland flow, sheet erosion, ponding and tillage erosion. Aggregate minimum diameter, i.e. the diameter of the smallest aggregates not integrated in the surface crust, also was directly assessed at the soil surface. As long as soil surface crust is developed, minimum diameter of soil aggregates outside this crust increases. Therefore this parameter can be used as a semiquantitative index of soil surface degradation by increased cumulative rainfall. Moreover, where significant rill erosion and/or sedimentation were observed, the site was surveyed for position of the channel and soil losses (Taboada Castro, 2001; Mirás Avalos et al., 2009).

Field identification of crust types and the associated state of degradation provided valuable information for predicting soil surface characteristics determining runoff, mainly infiltration and temporal storage capacity. Sedimentary crusts with a very low saturated conductivity (<5 mm/h) developed from freshly tilled surfaces after cumulative rainfall of about 150-200 mm (Mirás Avalos et al., 2009) or even after 50 mm (Taboada Castro, 2001). After a structural crust has been developed, infiltration capacity during heavy or moderate intensity rains can be about an order of magnitude lower than peak rain intensity. Therefore, field data are useful to evaluate the capacity of each land unit in the catchment to produce runoff and for modelling of concentrated erosion rates and risks (Figures 2, 3 and 4).

Runoff processes and runoff frequency at the catchment level have been found to show a wide complexity (e.g. Ludwig et al., 1996; Valcárcel et al., 2003) mainly depending on the interaction between soil properties influencing the structural state, agricultural practices and climate. For example, fields in long periods of rotation with corn showed high frequencies of runoff (Valcárcel, 1999).

On the other hand, runoff concentrates along features from topographical or agricultural origin. Man-made factors influencing runoff directions and runoff rate at the small catchment scale may be permanent (small roads and ditches) or temporary (ridges, dead furrows, etc.). In addition, size and geometrical configuration of farm fields also have been found to influence erosion rates. Therefore, field boundaries, headlands and dead furrows were mapped in field survey, independently from rill observations. Moreover land use data, including the nature of the crop, the rate of soil cover by growing vegetation and crop residues, the date, nature and direction of the farm operations have been also taken into account (Valcárcel, 1999). Actually, it is shown that rill lengths are determined by the route of the runoff and the location of the rill heads along the route. The route of the concentrated runoff is determined by topography and agricultural land use, which produce different types of linear depression features. These topographical and agricultural features form a runoff collector network which guides the flow to the catchment outlet (e.g. Ludwig et al., 1996).

Therefore, erosion rates have been explained taking into account the hydrographical structure of each catchment, which depends on both topography and lineal agricultural features. This is because concentrated flow erosion results from the hydrological connection between a runoff-contributing area where soil detachment does not necessarily occur and a collecting channel where flow discharge and velocity exceed the critical values for rill initiation and development. The hydrological structure of a catchment can be determined by identifying runoff collectors, runoff-contributing areas and the connection network between them (e.g. Auzet et al., 1993; Ludwig et al., 1996).

Both, analysis of concentrated soil erosion surveys and erosion modelling at the small catchment scale require information about soil surface stage and man-made features. Therefore, we focuses on several factors which depend on land use and land management and are thought to be most important for our study conditions: soil crusting, tillage direction, surface roughness, buffer strips and soil cover.

- *Soil crusting*. The stage of evolution of the soil surface has been shown to be associated with the hydraulic conductivity. A recent tilled soil is very permeable. Cumulative rainfall effects produce first a structural and finally a depositional or sedimentary crust. Sedimentary crusting affecting more than 80% of the soil surface has been observed mainly during two periods: in later spring after maize seedbed preparation and in autumn after grassland sowing.
- *Tillage* following the direction of maximum slope, on the one hand, increases flow velocity, causing a higher runoff peak and erosion rates and, on the other hand, reduces the surface storage capacity. Soil tillage perpendicular to the slope direction reduces flow velocity and increases surface storage capacity. Furthermore, which is most important, the drainage network can be fragmented, thus reducing the runoff contributing area. This is like dividing the total area, which originates runoff in smaller ones, producing less runoff and consequently less erosion. However, the link between tillage direction and runoff routing may be sometimes ambivalent: ridges and tracks created by tillage and seedbed preparation can be used as channels, thus promoting concentrated flow and increasing runoff flow velocity.
- *Surface roughness* has been found to change flow direction in catchments with gentle slope. After ploughing roughness is high, about 4 - 5 cm, but after seedbed preparation this figure is reduced to less than 1 cm with a high surface storage capacity, together a

high infiltration rate. Consequently, water depressional storage by microrelief can vary between 10-12 mm for a rough surface and less than 1 mm for a seedbed (Kamphorst et al., 2000).

- *Buffer strips* are a well-known conservation measure, thought not very much used in the area studied in this work. The effects of buffer strips are both, a reduction of the flow transport capacity and the increase of sedimentation. Hedges fences and ridges, left by certain cropping operations, such as digging up of potatoes have been observed to produce similar effects than border buffer strips at the field border.
- *Soil cover* by crop residues reduces the rainfall kinetic energy, diminishing soil detachment and crusting; on the other hand soil cover acts increasing roughness, thus reducing flow velocity.

3. Rates of soil erosion from field surveys

Several campaigns of concentrated erosion surveys have been conducted since 1996 in agricultural fields located at a 30-km radius from the town of A Coruña (Valcárcel et al., 2003; Mirás Avalos et al., 2009). Between 1996 and 2010 sedimentary crusts developed from freshly tilled surfaces even during the spring and autumn of 2004, which was the driest year of this time series. Concentrated flow erosion was observed during all the study period, except in autumn-early winter of 2004. Moreover, evidences of overland flow and more or less generalized interril erosion were observed during all the field survey campaigns of the studied time interval.

Table 1 list rainfall amounts from 1997 to 2004, whereas Table 2 shows average erosion rates during the same time period. For the sake of comparison, three subperiods were taken into account: 1997-2000, 2000-2001, which was the wettest year, and 2001-2004. Erosion rates during 1997-2000 were on average 3.29 Mg ha^{-1} year^{-1}. These figures are of the same order of magnitude than the 2.68 Mg ha^{-1} year^{-1} averaged for the 2001-2004 timespan. The somewhat greater values of 1997-2000 when compared with the 2001-2004 period are in accordance with the rather higher rainfall of the former. In between, the extremely wet year 2000-2001 yielded soil loss rates by concentrated flow erosion of 36.81 Mg ha^{-1} year^{-1}, thus about one order of magnitude greater than the average of the other years studied (Mirás Avalos et al., 2009).

Period	**1997/98**	**1998/99**	**1999/2000**	**2000/01**	**2001/02**	**2002/03**	**2003/04**
April 1 – June 30	329.0	435.4	249.0	268.0	159.0	242.0	201.0
July 1 – September 30	78.8	122.3	207.0	172.0	160.0	102.0	130.0
October 1 – December 31	475.5	214.1	580.0	747.0	196.0	731.0	524.0
January 1 – March 31	138.4	365.1	117.0	622.0	297.0	289.0	143.0
April 1 – March 31	1021.7	1136.9	1153.0	1809.0	812.0	1364.0	998.0

Table 1. Yearly and quarterly rainfall from 1997-1998 to 2003-2004 at the studied site (units in mm).

Summarizing, in our study area, the main situations of concentrated flow erosion that can be roughly distinguished are:

- No incision or limited rill incision, i.e., below 2 Mg ha^{-1} year^{-1} as, for example, in autumn-early winter and spring of 2004, respectively.

- Generalized rill and limited ephemeral gully incision in the class of mean values between 2.5 to 6.25 Mg ha^{-1} year^{-1}. In this case, the contribution of each unit is very variable, ranging from about 1 Mg ha^{-1} year^{-1} to 31 Mg ha^{-1} year^{-1}. This was the most common erosion pattern during the study period and was illustrated by observations in spring and autumn 1999, autumn 2002, and spring 2003 and 2004 (see Figures 2 and 3b as examples).
- Generalized ephemeral gully incision, which was observed during the extremely wet winter period, between October 2000 and February 2001. Again, the between site differences in erosion rates were large, ranging from 3.0 to 62.5 Mg ha^{-1} year^{-1}. Figure 4 shows an example of heavy erosion observed in February 2001. Notice that erosion was so heavy during this period that not only the topsoil was removed but also the uppermost B horizon was affected.

Period	**Surface**	**Rill + gully**	**Rills**	**Ephemeral Gullies**	**Gully/(rill + gully)**
	(ha)	(Mg ha^{-1} year^{-1})	(Mg ha^{-1} year^{-1})	(Mg ha^{-1} year^{-1})	(%)
1997-2000	36.8	10.01	7.36	2.65	26.4
	Average concentrated erosion rate= 3.29 Mg ha^{-1} year^{-1}				
2000-2001	10.8	397.6	46.04	351.56	88.4
	Average concentrated erosion rate = 36.81 Mg ha^{-1} year^{-1}				
2001-2004	53.5	8.05	6.29	1.76	21.9
	Average concentrated erosion rate = 2.68 Mg ha^{-1} year^{-1}				

Table 2. Average soil losses by concentrated erosion (rills and gullies) during subperiods of the 1997-2004 time span.

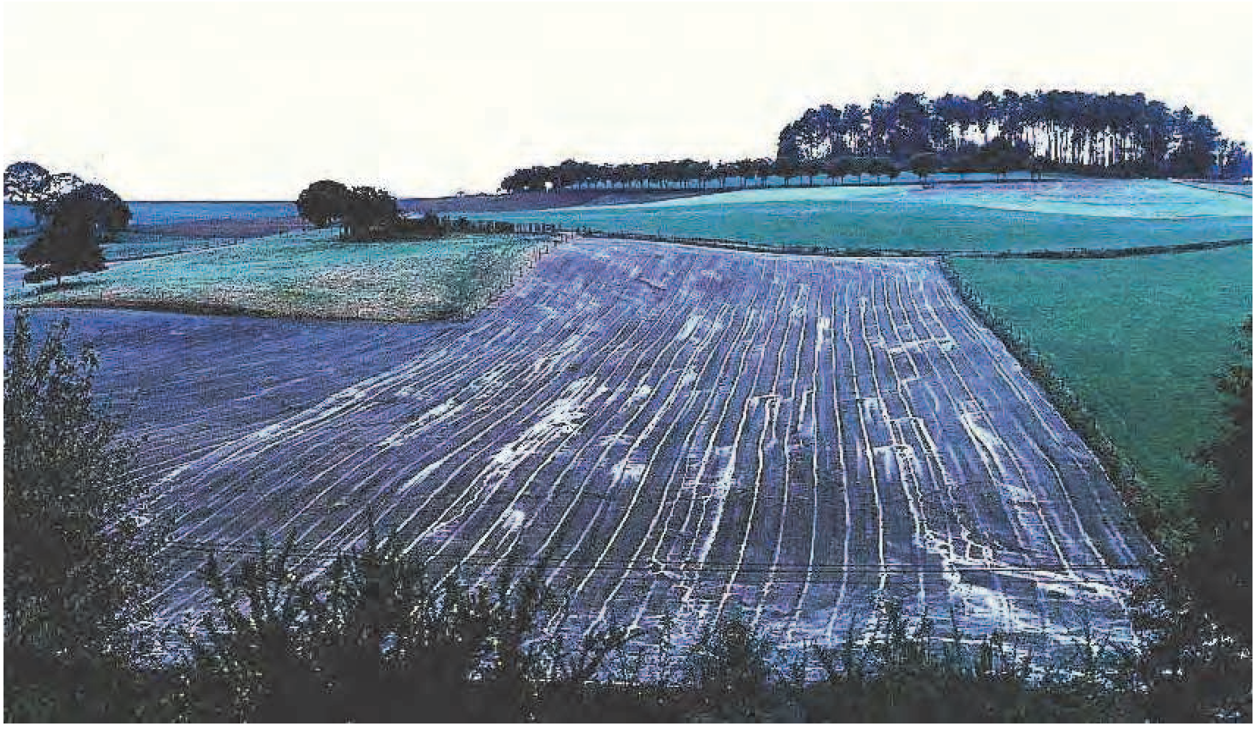


Fig. 2. Extensive rill erosion on a seedbed at a hillslope.

(a)

(b)

Fig. 3. a) Partial crusting at the soil surface and b) Crusting and rill initiation.

Fig. 4. Gully showing topsoil and subsoil erosion during a heavy erosion period in winter 2000-2001.

Erosion caused by ephemeral gullies supposed 26.4% of total soil losses during 1997-2000 and 21.9% during 2001-2004. Nevertheless, this ratio was much higher during the extremely rainy period of 2000-2001, accounting for 88.4% of total soil losses. Therefore, increased total concentrated flow erosion increases the proportion of ephemeral gully erosion.

The highest risks of concentrated erosion observed during the period of study were found for the following conditions: i) tilled surfaces prepared as seedbeds for in spring, and ii) surfaces also prepared as seedbeds for winter cereal or prairie renovation in autumn-early winter. This matched periods with a high proportion of sedimentary crusting (Valcárcel et al., 2003).

Survey results also showed important differences between ploughed soils and seedbeds, as no significant concentrated flow erosion was found in the former, even with high amounts of rainfall. The absence of runoff generation in the mouldboard ploughed surfaces can be attributed to the important temporal storage capacity in microrelief depressions, which are associated with the high roughness produced by ploughing. Depressional storage of rough surfaces can reach more than 10 mm m^{-2} (Kamphorst et al., 2000). In opposite, because of the low surface roughness, spring and autumn-tilled surfaces, left bare produced high rates of concentrated flow erosion as shown by measurements done at summer beginning or at the end of the winter, respectively.

Grassland is sowed in autumn on seedbeds with low roughness values, which also resulted in topsoil surface prone to crusting, where runoff was frequent. However, once a protecting soil cover developed, grassland prevented totally concentrated flow erosion. Because a temporal prairie protects the soil surface for a length of three or four years, concentrated flow erosion risk was highly reduced when rotations included temporal pastures.

4. Modelling soil losses and runoff at the catchment scale

Erosion models consist of mathematical equations that compute estimates of soil loss, together with sediment yield, runoff and sometimes even water quality. These models require input values for climate, topography, soil and land use. Since more than half a century, many erosion models are available, each with particular strengths and limitations (e.g. Toy et al., 2002). Because rainfall, soil, topography and land use vary across a region or a catchment, soil losses and associated variables also show considerable spatial variability. Nowadays most erosion models can be applied in a spatially distributed way, which improves the accuracy of erosion estimations.

Several models have been developed for the purpose of estimating erosion and runoff at the scale of small agricultural catchments. Well-known examples are: CREAMS, ANSWERS, AGNPS, KINEROS, WEPP, EUROSEM and LISEM. Such models perform simulation of water losses and soil losses on the basis of meteorological information, crop phenology, agricultural practices and the physical characteristics of the watersheds. In the last decades they have played an outstanding role in hydrological planning and management at the catchment scale.

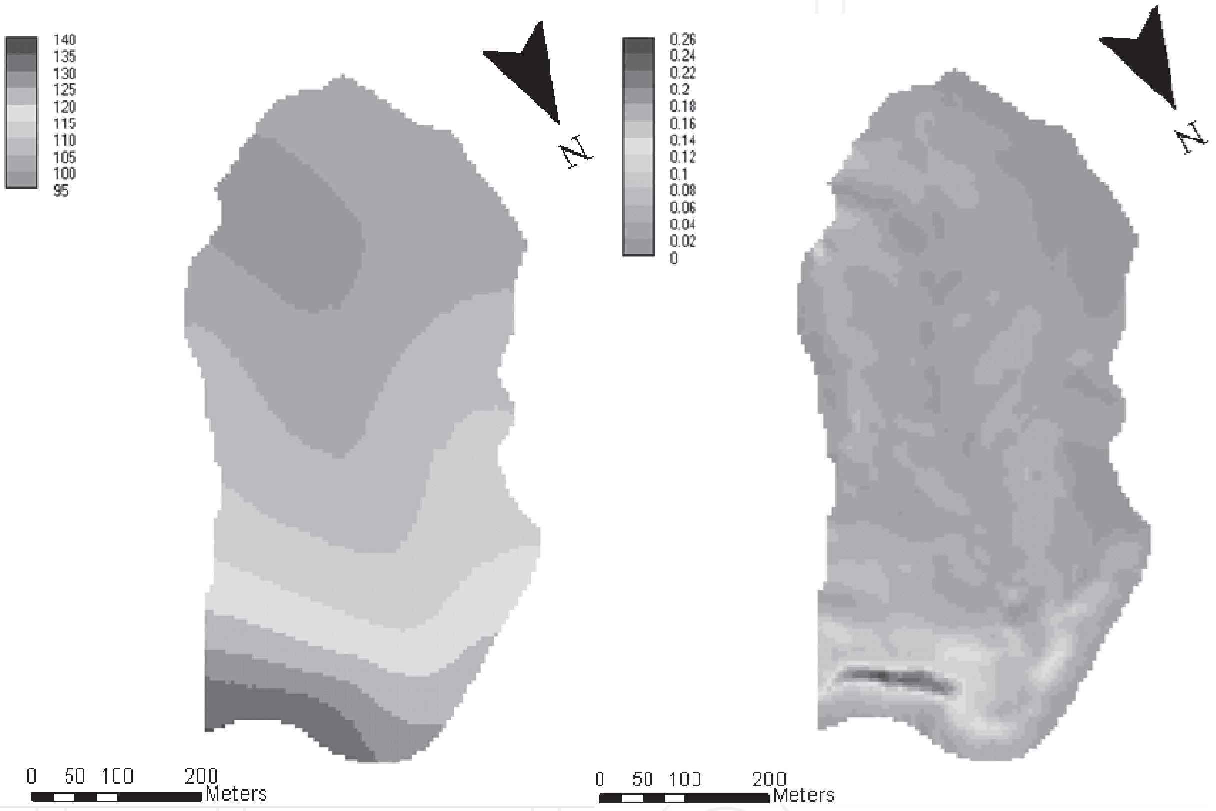
Distributed models discretize the physical medium in cells of required size, aiming recreation of the main processes of the hydrological cycle. The discretization process allows taking into account water balance and the transfer processes for each cell into which the catchment is divided. Furthermore, distributed models also are able to analyze the hydrological variables and parameters in such a way that the spatial variability found in agricultural catchments is reproduced. This is a very important issue, because parameters such as infiltration rates in cultivated fields change spatially and temporally, in relation with changes of the soil surface condition. However, accurate description of agricultural catchment where the main type of land use is arable cropping remains not easy, because of the large temporal and spatial variability.

LISEM (De Roo and Wesseling, 1996) is a physically based distributed model that estimates erosion at the catchment scale during a rainfall event. The main achievement of LISEM was that the model is fully integrated into a raster geographical information system (GIS) known as PCRaster (Van Deursen and Wesseling, 1992). This model allows assessing the effects of land use changes and to explore several soil conservation scenarios. Moreover, this distributed model pay particular attention to the influence of man-made factors, such as small roads, tillage direction and wheeltracks, and conservation measures, such as grass strips. Examples of tillage factors that can be responsible for the modification of runoff direction are tillage direction, dead furrows, dirt tracks and surface roughness.

4.1 Scenario building

Several scenarios were taken into account in our study. All of them used the topography of an agricultural catchment representative of the main conditions of the Ordenes complex area. This catchment is located at Mabegondo (Coruña province) and it is about 25 ha in surface with an average slope 4.17%. Moreover, scenarios were based on rotation schemes, agricultural operations and soil properties gathered during field surveys.

Topography measurements were made by means of an Abney level. Using PCRaster a digital elevation model (DEM) was elaborated, from which basic spatial catchment information was derived. Figure 5 shows DEM (a) and slope maps (b) of the Mabegondo catchment, with a grid size of 5 m x 5 m. The Mabegondo catchment was considered to be divided in 5 fields (Figure 6a). Land use in the field at the uppermost part (number one) was assumed to be grassland and the remaining fields (number two to five) were assumed to be cultivated with maize.



(a) (b)

Fig. 5. Mabegondo catchment: a) Digital Elevation Map (DEM) and b) Slope map.

In this work the LISEM 1.55 version for Windows (Jetten al., 1999) was utilized. The main processes incorporated by the model are: interception, surface storage, infiltration, runoff routing, splash detachment, flow detachment, channel flow, transport capacity of the flow and sediment routing (De Roo and Wesseling, 1996). Last versions of this model pay special attention to the influence of surface sealing, tillage direction and tillage features, like wheeltracks. Several methods may be chosen optionally to calculate infiltration: Green-Ampt (one or two layers), Richards and Holtan. In this work the Green-Ampt equation was used to assess infiltration into one layer soil. Surface storage in micro-depressions was estimated from the random roughness and the slope data.

An input dataset for LISEM consists of a series of raster maps, including:

- Maps based on topography: slope and local drainage direction.

- Land use maps: agricultural drainage network, surface cover, leaf area index, roads, etc.
- Maps with soil hydrological variables: saturated conductivity, initial moisture content, etc.
- Maps for describing soil surface: random roughness, hydraulic resistance, cohesion and aggregate stability.

The scenarios to be simulated roughly represent agricultural and soil conditions during a wet spring, after maize seedbed preparation. The soil surface is expected to have reached an important degree of evolution, similar to the first stage of a sedimentary crust. Information about values assumed for several input parameters at the five fields of the studied catchment are listed on Table 3. So, infiltration and random roughness were considered to be uniform within each field, even if natural variability was observed during our surveys. From the available experimental information, saturated conductivity was considered to be 5 mm h^{-1} for maize seedbeds and 30 mm h^{-1} for grassland (González García, 1999; Taboada Castro, 2001) and random roughness was fixed at 1.2 mm for grassland and 0.9 cm for maize seedbeds (Vidal Vázquez, 2002). In addition, the model requires data sets for initial moisture deficit, Manning n parameter, median diameter of particle size distribution (D50), aggregate stability, cohesion and soil cover, which also are shown in Table 3.

Field N°	Area (ha)	Crop	Moisture Deficit	Ksat (mm/h)	Wheeltracks		
					Distance (m)	Width (m)	Depth (cm)
1	7.00	Grassland	0.03	30			-
2	1.88	Maize	0.03	5	12	0.4	2
3	6.65	Maize	0.03	5	12	0.4	2
4	1.96	Maize	0.03	5	12	0.4	2
5	7.49	Maize	0.03	5	36	0.4	2

Field N°	Manning n	D50 (μm)	RR (cm)	Agg.	Cohesion (kPa)	Soil Cover (%)
1	0.2	65	1.2	-	3.25	90
2	0.07	40	0.9	20	0.9	0
3	0.07	40	0.9	20	0.9	0
4	0.07	40	0.9	20	0.9	0
5	0.07	40	0.9	20	0.9	0

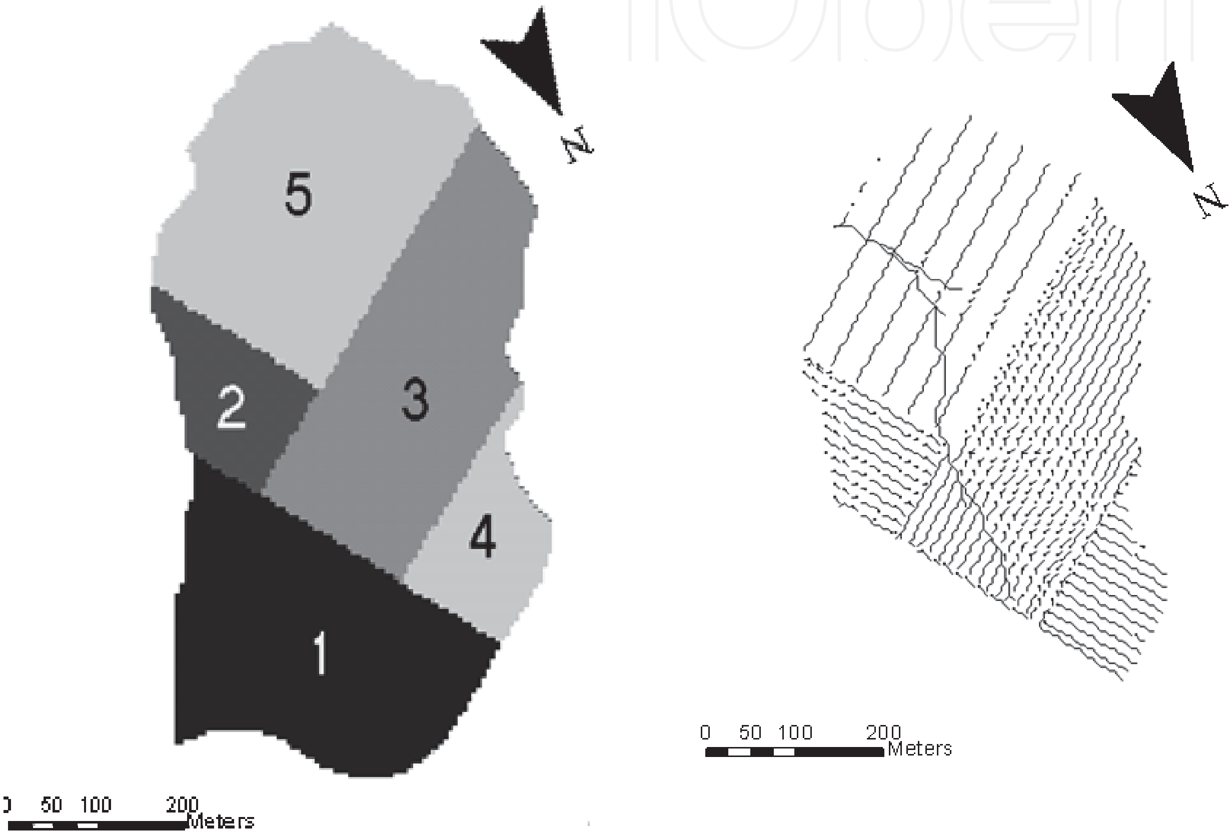
Table 3. Information about land use in the Mabegondo catchment and parameters used for each of its five fields in simulating runoff scenarios (Ksat = Hydraulic conductivity; RR = Random roughness; Agg. = Aggregate stability).

Simulations were carried out using synthetic storms for two different return periods, two and twenty-five years. These were built using the alternate block method, with intensity-duration-frequency data for A Coruña.

Main output of the model are erosion and sedimentation maps, a summary balance file with totals for different simulated terms (total rainfall, total discharge, peak discharge, total soil loss, etc.) and a time series file with information about discharge, solid discharge and sediment concentration in the catchment outlet. Optionally, also runoff maps at imposed intervals during the simulated event.

4.2 Predicting the effect of soil conservation measures and tillage features

As examples, next we show results for the simulated effect of grass strips at the borders of the cultivated fields and for taking into account wheeltracks as runoff channels. We assumed a 2 m width of the buffer strip, whereas wheeltracks of 0.4 m width and 2 cm depth were defined along the field largest side at 12 m intervals (Figure 6b, Table 3). Four scenarios were analyzed: 1) neither wheeltracks, nor buffer strips, 2) buffer strips and no wheeltracks, 3) wheeltracks and no buffer strips and 4) buffer strip plus wheeltracks.



(a) (b)

Fig. 6. a) Mabegondo catchment: a) Distribution of the five fields used for scenario building and b) Map showing the position of wheeltracks on the four tilled fields. Topographical channels are also depicted.

Results are summarized in Table 4. Total runoff, peak runoff and erosion rates were very higher for scenarios with 25 year return period compared to those with a 2 year return period, which is an obviously expected result. Grass strips at the field borders decreased the discharge at the outlet of the catchment from 435.46 to 327.32 m^3 and from 3360.14 to 3174.60 m^3 for a two year and a twenty-five return period, respectively. In terms of discharge/rainfall ratios the reduction was from 9.29% to 6.99% and from 34.18% to 32.30%, respectively. Peak discharge also decreased for the two studied rainfall scenarios. For rainfall intensities with a two year return period erosion rates were less than 1 Mg ha^{-1}, whereas for a twenty-five years return period erosion rates were between 4 and 5 Mg ha^{-1}. Erosion rates when grass buffers are used would be reduced by 45.6% and 16.5% for rainfall intensities with two and twenty-five years return periods, respectively.

Scenario	Without grass strips and without channels		Grass strips		Wheeltracks as channels		Grass strips + Wheeltracks as channels	
Return period (years)	2	25	2	25	2	25	2	25
Total Rainfall (mm)	18.76	39.35	18.76	39.35	18.76	39.35	18.76	39.35
Total Infiltration (mm)	16.64	25.38	17.08	26.06	15.62	24.12	15.89	24.49
Total Discharge (m^3)	435.46	3360.14	327.32	3174.60	690.08	3.673.92	622.43	3581.18
Peak Discharge (l s^{-1})	235.43	1965.85	142.67	1373.09	518.79	2553.71	418.22	2183.77
Discharge/ Rainfall (%)	9.29	34.18	6.99	32.30	14.73	37.32	13.28	36.43
Average Soil Loss (kg ha^{-1})	685.59	5174.36	470.79	4441.32	1497.60	13491.42	1224.59	13255.09

Table 4. Summary of simulated results for scenarios taken into account the effect of grass strips or/and wheeltracks.

When wheeltracks are modelled as channels allowing runoff routing, both total and peak discharge considerably increase. The discharge/rainfall ratio rises from 9.29% to 14.73% for a two year return period and from 34.18% to 37.32% for a twenty-five year return period, indicating that in relative terms channelling effects are more important in the former than in the later scenario. Peak discharge also rises comparatively more for the two year return period than for the twenty-five return period. Also average soil losses are more than two times higher when wheeltracks are taken into account, increasing from 0.69 to 1.50 Mg ha^{-1} for a storm with a two year return period and from 5.17 to 13.49 Mg ha^{-1} for a twenty-five year return period storm. Therefore, according with the simulation results wheeltracks effects are greater on soil losses than on water losses at the catchments scale. Taken into account tillage features for scenario building and assuming parameters (infiltration, surface roughness) corresponding to a crusted soil surface, soil loss results are of the same order of magnitude than those based on field surveys.

The use of grass strips in the scenario with wheeltracks somewhat reduces runoff and erosion rates, as expected, but the effect of this conservation measure is rather limited. So discharge/rainfall ratio decreases from 14.73% to 13.28% under the two-year return period scenario and from 37.32 to 36.4% under the twenty-five years scenario.

The above results show that erosion simulation using a distributed model is able to take into account the hydrological structure of the studied unit (i.e. a hillslope or a catchment), which should provide further insight to analyze the variability of erosion by concentrated flow. This way allows an adequate assessment of the total erosion rate. Moreover, using some simplifying hypothesis distributed models can help in identifying runoff collectors and runoff contributing areas.

Both, field observation and modelling provide complementary information, which allow overcoming the scarce information on concentrated flow erosion in the regions of Atlantic

Spain and should be useful for a sustainable management of agricultural land with the aim of reducing water erosion risks.

5. Summary and concluding remarks

Regions along the Atlantic coast in Northern and Northwest Spain are characterized by humid, temperate climate. Rain intensities are moderate to low, lower than in Mediterranean regions. In our study area, traditional agricultural systems were characterized by the small size of fields and by a wide system of terraces with stone walls and various border features, separating the individual fields. For several centuries thousands of kilometres of walls acting as terraces have been constructed at the field boundaries and they have been an important element in erosion control. In the last decades, properties have been redistributed increasing the average field size and facilitating intensive farming practices. Attention has been paid to agricultural soil erosion not because of concern for loss of soil fertility, but rather because of nutrients losses. In spite of the relatively low erosivity, concentrated flow erosion is widespread on agricultural fields and/or small catchments. Increasing surveys on soil erosion from agricultural land at the field and catchment scale that rill erosion is a common feature in most of the years, whereas in some years heavier gully erosion occurs. Thus, concentrated flow erosion has been demonstrated to be the most important water erosion type in Galicia and other regions of North Spain, which is in agreement with erosion features before described other areas of Atlantic Europe.

Cropping systems are partly responsible for concentrated flow erosion, which may become a severe environmental problem. Interactions between farm operations, climate and soil texture induce complex and rapid changes in topsoil structure and its hydraulic properties. For example, it has been shown that properties determining the capacity of the land to produce runoff, such as soil infiltration and surface storage are strongly dependent on the crusting of the soil surface layer. Concentrated flow erosion most frequently takes place on seedbeds and recently tilled soils in late spring and autumn or early winter, but heavier erosion episodes may occur in every season when the soil surface is left bare. In most of the studied cases ephemeral gully erosion may cause significant soil loses, ranging from 2 to 5 Mg ha^{-1} for a single season; however locally erosion rates may reach between 25 and 50 Mg ha^{-1}.

A modelling approach was used to predict erosion at the catchments scale for a given event. This model is spatially distributed, so that it allows taking into account interaction within different fields in runoff production and soil losses. The input data are topography rainfall characteristics, soil surface state and other soil physical properties (infiltration, surface roughness, etc.). The influence of field geometry, agricultural features at the field border (for example headlands and dead furrows), tillage marks (for example wheeltracks) and conservation practices (for example buffer strips) that influence runoff and soil losses can also be analyzed by the model. Both, field observation and modelling provide complementary information, which allow overcoming the rather scarce knowledge on concentrated flow erosion in North Western Spain and are thought to be useful for a sustainable management of agricultural land with the aim of reducing water erosion risks.

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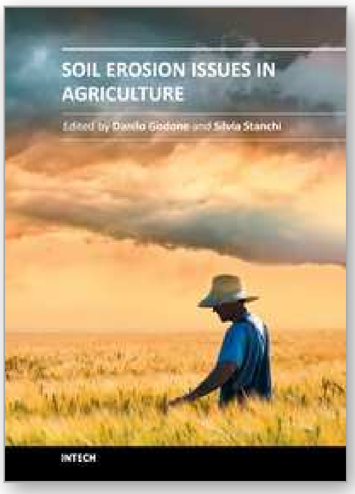

Soil Erosion Issues in Agriculture
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The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.

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InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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Unit 405, Office Block, Hotel Equatorial Shanghai
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中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821