2.4

Sheet and Rill Erosion

Olivier Cerdan,[1] Jean Poesen,[2] Gérard Govers,[2] Nicolas Saby,[3] Yves Le Bissonnais,[3] Anne Gobin,[2] Andrea Vacca,[4] John Quinton,[5] Karl Auerswald,[6] Andreas Klik,[7] Franz F.P.M. Kwaad[8] and M.J. Roxo[9]

[1]*BRGM-ARN Aménagement et risques naturels, 3, av. Cl. Guillemin - BP 6009, 45060 Orléans Cedex 2 - France*
[2]*Physical and Regional Geography Research Group, Katholieke Universiteit Leuven, GEO-Institute, Celestijnenlaan 200 E, 3001 Heverlee, Belgium*
[3]*INRA-LISAH, Campus AGRO, Bat. 24 - 2 place Viala - 34060, MONTPELLIER Cedex 1 - France*
[4]*University of Cagliari, 090402 Monserrato (Cagliari), Italy*
[5]*Department of Environmental Science, University of Lancaster, Lancaster LAI 4YW, UK*
[6]*Lehrstuhl für Grünlandlehre, Technische Universität München, 80333 Munich, Germany*
[7]*University of Natural Resources and Applied Life Sciences, Gregor Mentde Strasse 33, 1180 Vienna, Austria*
[8]*University of Amsterdam, Postbus 19268, 1000 GG Amsterdam, The Netherlands*
[9]*Universidade Nova de Lisboa, 1649-004 Lisbon, Portugal*

2.4.1 INTRODUCTION

Water erosion is commonly divided into different subprocesses. This chapter focuses on erosion processes ranging from sheet (or interrill) erosion, which consists of the removal of a fairly uniform layer of soil by raindrop splash and sheet flow, to rill erosion, which results in the formation of numerous and randomly occurring small channels of only several centimeters depth under the action of small, intermittent water courses usually also only several centimeters deep (Glossary of Soil Science Terms, http://www.soils.org/sssagloss). To measure the rates and extent of sheet and rill erosion, both indirect and direct methods have been used. Indirect methods generally measure soil profile truncation or sediment accumulation relative to a reference soil horizon, to an exposed or buried reference object (exposed or buried roots, foundations, etc.), or to the loss or accumulation of tracers. These methods are more appropriate for studying historical erosion. To

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assess current sheet and rill erosion rates, direct methods, mainly plot or catchment monitoring and field-based measurements (e.g. mapping of erosion features) are reported. Field-based methods are most effective to answer questions such as, where does linear erosion occur and is it a problem? However, they cannot properly monitor sheet erosion and, more important for this study, their applications have been restricted to very few places in Europe. The best available data to compare soil erosion rates in Europe induced by sheet and rill processes come from plot measurements. These represent relatively well-standardized data, which can give reliable information on slope sensitivity to sheet and rill erosion under a given set of conditions, and they are widespread. Based on a large dataset of soil erosion measurements under natural rainfall at the plot scale, the objectives of this study were (i) to quantify the different sheet and rill erosion rates in various agro-environmental settings throughout western and central Europe, (ii) to identify the more at-risk situations in terms of land use or physiographic conditions and (iii) to assess overall sheet and rill erosion rates for Europe.

2.4.2 METHODOLOGY

An extensive database of short- to medium-term (1–10 years) soil loss measurements at the plot scale was compiled from the literature. This database contains 208 entries (one entry corresponds to the combination of one land use, slope, etc., for one experimental site) distributed among 57 experimental sites in 13 countries, representing a total of 2162 plot-years. Only data from experiments with a direct measurement of soil erosion rates, i.e. with an experimental device to measure erosion during natural rainfall events, were collected (e.g. collecting tanks or tipping buckets with or without automatic samplers). On average, the experiments cover ~10 equivalent (eq.) plot-years with a median of 6 plot-years per entry, the maximum being for cereal plots in Portugal (96 eq. plot-years; Lopes *et al.*, 2002) and in Germany, where bare plots have been monitored for 60 eq. plot-years (Martin, 1988; Auerswald, 1993). As shown in Figure 2.4.1 and Table 2.4.1, the database is composed of sheet and rill erosion rate measurements from Austria, Belgium, Denmark, France, Germany, Greece, Italy, Lithuania, The Netherlands, Portugal, Spain, Switzerland and the UK. The corresponding annual rainfall in the database range from <200 mm (Spain) to >1300 mm (Germany), with a median annual value of 595 mm. No restriction regarding slope length was made when selecting the experimental sites as long as the land use was uniform. However, the median size of the plots is close to the Wischmeier plots with a median slope length of 20 m, a median area of ca 60 m^2 and a median slope of 13.2 % (94 and 75 % of the entries have a slope length >5 and 9 m, respectively, which are two recognised thresholds for rill initiation and development).

To compile the database, data with a similar location, land use, slope, slope length, area and soil texture (five classes) were aggregated (weighted for plot years of measurements). As a consequence, data were combined even if other parameters that influence the erosion response were different, for example, data showing differences in soil types or soil surface properties which are not reflected in the textural classification used, difference in tillage systems or direction (parallel or perpendicular to the contour) or differences in slope aspects. Experimental data where a strong evolution with time (e.g. Francia *et al.*, 2002) was reported were not included in the database, as it was difficult to calculate a relevant mean value.

2.4.3 RESULTS AND DISCUSSION

The mean sheet and rill erosion rates are presented in Table 2.4.2 and Figure 2.4.2. The erosion responses between the different land use classes differ significantly (Kruskal-Wallis test statistics = 79.1 with probability <0.0001). If we rank (in descending order) the land use classes with at least 25 eq. plot-years of measurement according to the observed sheet and rill erosion rates, we obtain bare soil, vineyard, maize, spring crops, cereal, post-fire, forage, shrubs, grassland and forest. Bare soil is the most represented class with 563 eq. plot-years and, with the vineyard class, have the highest mean rates (23.4 and 20 t ha^{-1} yr^{-1} respectively). Maize

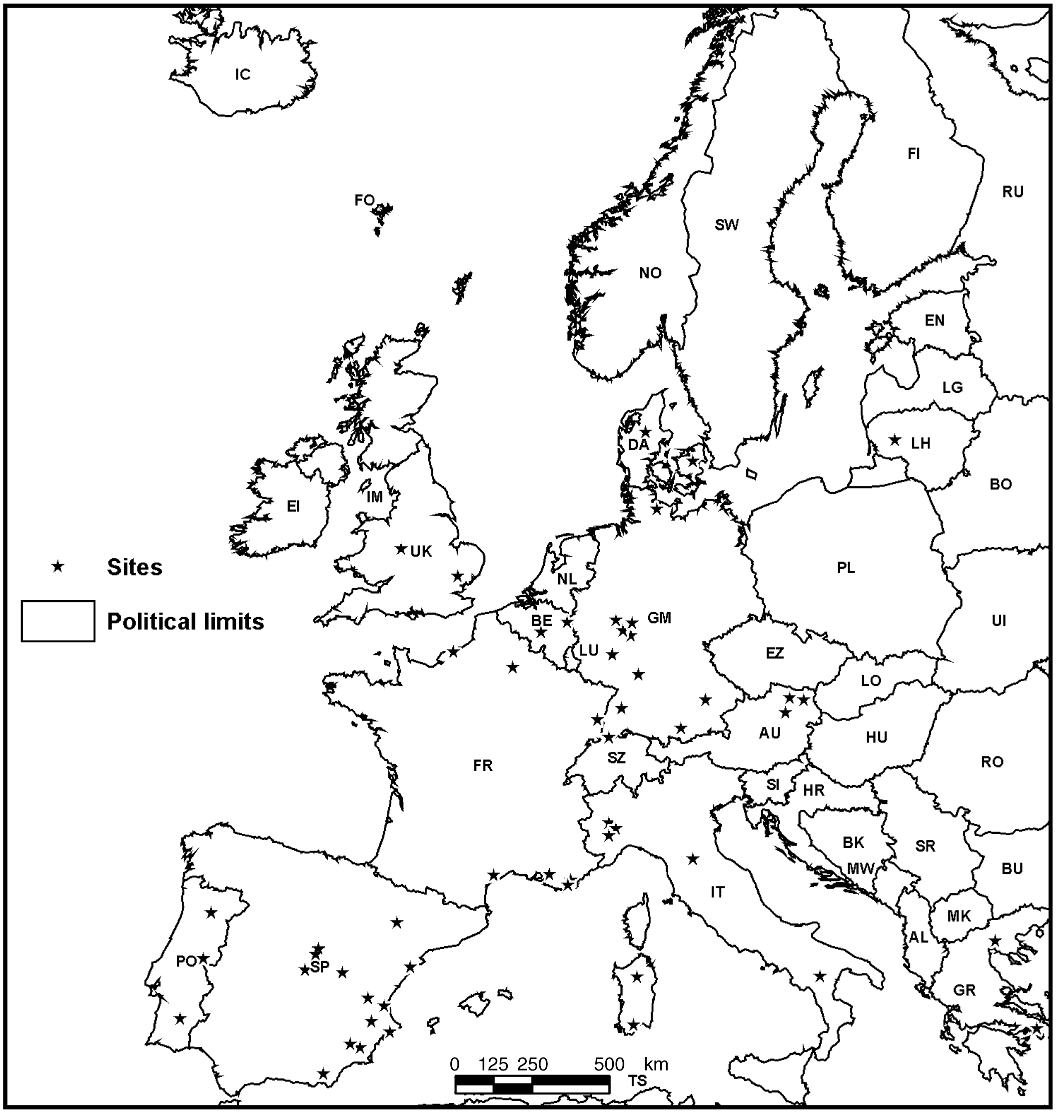

Figure 2.4.1 Location of the experimental sites used in this study

and spring crops also show very high rates, i.e. more than 10 t ha^{-1} yr^{-1}. Interestingly, spring crops have the highest mean yearly rainfall amount (749 mm) and a relatively low mean yearly runoff (~16 mm), which also imply high sediment concentration. Cereal, post-fire and forage have moderate rates of ~1.5 t ha^{-1} yr^{-1}. Despite relatively steep slopes, the classes shrubs, grassland and forest have the lowest rates, i.e. $<$1 t ha^{-1} yr^{-1} and have relatively high mean yearly runoff volumes, which, conversely to spring crops, imply very low sediment concentration. In fact, land uses with the highest percentage of bare soil, either spatially (wide interrow length and low leaf cover, e.g. vineyard or maize) or temporally (long intercrop duration, e.g. maize or spring crop) have the highest rates. The assemblage of these plot data in a database

TABLE 2.4.1 Description of the soil erosion plot database

Country	No. of entries[a]	Total eq. plot-year	Mean eq. plot-year	References
Austria	8	43	5	Klik *et al.*, 2001; Klik, 2003
Belgium	3	31	10	Bollinne, 1982
Denmark	6	16	3	Veihe and Hasholt, Chapter 1.4
France	11	59	5	Viguier, 1993; Messer, 1980; Martin *et al.*, 1997; Bissonnais 2004; Cerdan *et al.*, 2002; Clauzon and Vaudour, 1971
Germany	41	400	10	Martin, 1988; Auerswald, 1993; Goeck, 1989; Goeck and Geisler, 1989; Dikau, 1986; Voss, 1978; Emde, 1992; Jung and Brechtel, 1980
Greece	8	48	6	Kosmas *et al.*, 1996; Romero-Diaz *et al.*, 1999; Diamantopoulos *et al.*, 1996
Italy	33	433	13	Tropeano, 1983; Zanchi, 1983; 1988; Rivoira *et al.*, 1989; Porqueddu and Roggero, 1994; Caredda *et al.*, 1997; Vacca *et al.*, 2000; Basso *et al.*, 2002
Lithuania	11	134	12	Jankauskas and Jankauskiene, 2003
The Netherlands	3	35	12	Kwaad, 1991; 1994; Kwaad *et al.*, 1998
Portugal	16	482	30	Roxo, *et al.* 1996; Figueiredo *et al.*, 1998; Lopes *et al.*, 2002
Spain	48	367	8	Andreu *et al.*, 1994 cited by Cerdà 2001; Bautista *et al.*, 1996; Bautista, 1999 cited by Cerdà, 2001; Andreu *et al.*, 1998a & b; Andreu *et al.*, 2001; Sirvent *et al.*, 1997; La Roca, 1984 cited by Cerdà 2001; Castillo *et al.*, 1997; Puigdefabregas *et al.*, 1996; Padron *et al.*, 1998; Romero-Diaz *et al.*, 1999; Lopez-Bermudez *et al.*, 1991; 1998; Canton *et al.*, 2001; Nicolau *et al.*, 2002
Switzerland	2	9	5	Schmidt, 1979
UK	18	104	6	Fullen and Reed, 1986; Fullen, 1991; 1992; Quinton, 1994

[a]One entry corresponds to the combination of one land use, slope, etc., for one experimental site.

allows comparison of the impact of very different land uses in a common framework and thus confirm ideas that were commonly assumed about the sensitivity of certain crops (e.g. maize, spring crops) to sheet and rill erosion. However, as always with results directly deduced from an experimental dataset, the limits concerning the representativeness of this database should be questioned. Two types of limits can be highlighted:

1. *Limits related to spatial representativeness*

Even if the database is rather extensive, good-quality long-term plot data are not available for every agro-ecological zone in Europe. For example, values up to 200 t ha^{-1} per rainfall event were observed in southwest France (Le Bissonnais *et al.*, 2003) for high-intensity storms on agricultural areas with low vegetation density, but no long-term plot studies have ever been conducted in this area (some possibly high-risk crops as hop or vegetable are also missing from the plot database). Some plot studies are set up systematically according to predefined large monitoring schemes (e.g. Wischmeier plots with different soil types, tillage systems or crop rotations) whatever the erosion risk and are therefore rather objective. On the other hand, other plot studies might stress a particularly at-risk area. In the latter case, extrapolation of results without careful attention to the specificity of the site can lead to an overestimation of the problem.

TABLE 2.4.2 Description of the soil erosion database aggregated according to land use

Land use	No. of entries[a]	Equivalent plot-year	Mean area (m^2)	Mean slope (%)	Mean rainfall ($mm\ yr^{-1}$)	Mean slope length (m)	Mean runoff ($mm\ yr^{-1}$)	Mean erosion ($t\ ha^{-1}\ yr^{-1}$)
Bare soil	54	563	60.0	15.9	674	14.4	91.7	23.40
Vineyard	10	113	100.3	19.3	629	52.3	80.8	19.97
Maize	6	27	38.1	9.9	676	12.9	63.7	13.95
Spring crop[b]	13	62	375.8	11.0	749	43.4	16.1	10.64
Maize + cover	3	21	21.2	8.7	560	10.9	19.9	2.65
Cereal	36	335	1641.2	12.7	629	37.7	19.3	2.10
Post-fire	8	112	1859.0	28.7	466	11.3	40.2	1.54
Forage	9	192	500.2	17.3	661	34.7	27.6	1.35
Vineyard + grass	5	12	102.5	24.0	598	62.7	17.1	0.78
Arable crops	6	139	16.0	10.8	862	8.0	42.2	0.53
Shrubs	34	283	65.3	22.1	411	16.2	9.5	0.50
Grassland	16	231	179.5	15.9	623	31.5	15.2	0.29
Barley + cover	1	3	66.3	10.0	665	22.1	—	0.28
Forest	6	51	48.7	19.9	483	11.8	6.0	0.10
Orchard	1	18	30.0	19.0	467	10.0	0.7	0.05
Total/mean	208	2162	466	16.4	609	25.7	41.0	8.76

[a]One entry is the combination of one land use, slope, etc., for one experimental site.
[b]Except maize, maize + cover and barley + cover classes.

2. *Limits related to the representativeness of the sheet and rill erosion processes*

Erosion is a scale-dependent process hence, depending on the size of the monitoring schemes, results differ, one reason being the influence of slope length, relief patterns or the spatial variability in soil surface conditions on the balance between sediment transport and deposition. Plot studies, being limited in space, will therefore

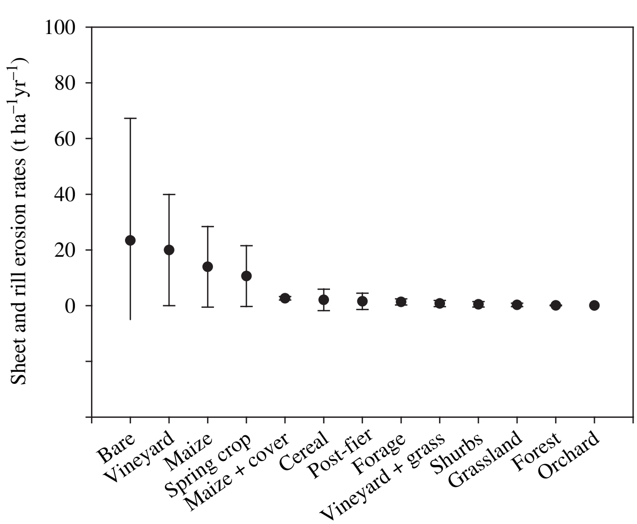

Figure 2.4.2 Mean (±SD) sheet and rill erosion rates aggregated per land use

not reflect everything about what is happening in the landscape in terms of sheet and rill erosion. The results should be understood as a comparison of the sensitivity of given slopes to sheet and rill erosion in a given set of conditions. However, whether the observed soil losses will leave the field or catchment where they originate or will be deposited needs to be addressed through further investigations. On most soil loss plots, the combined effect of interrill and rill erosion is measured. Most of the time, the relative contribution of rill against sheet erosion to the total soil loss remains unknown.

2.4.3.1 Geographical Distribution of Soil Losses

Numerous observations cover the Mediterranean zone, 1382 eq. plot-years data for 113 entries against 780 plot-years for 95 entries for the rest of Europe (Table 2.4.3). Overall, the sheet and rill erosion rates for the Mediterranean zone (MZ) are comparable to those of the rest of Europe.

In the MZ, rates are higher for bare soils (~32 t ha^{-1} yr^{-1} for the MZ against 17.3 t ha^{-1} yr^{-1} for the rest of Europe) but lower for most of the crop types, although the slopes are steeper. One possible explanation for these differences in the mean sheet and rill erosion rates for the crops (e.g. 0.7 t ha^{-1} yr^{-1} for cereals in the MZ

TABLE 2.4.3 Description of the soil erosion database aggregated according to location and land use

Zone	Land use	No. of entries	Equivalent plot-year	Mean area (m^2)	Mean slope length (m)	Mean slope (%)	Mean rainfall (mm yr^{-1})	Mean runoff (mm yr^{-1})	Mean erosion (t ha^{-1} yr^{-1})
Mediterranean	Bare soil	23	246	113.9	21.0	18.0	559	90.6	31.62
	Vineyard	6	101	99.4	32.2	16.4	640	116.4	16.64
	Vineyard + grass	2	6	100.0	41.8	23.5	582	33.3	1.92
	Post-fire	8	112	1859.0	11.3	28.7	466	40.2	1.54
	Forage	9	192	500.2	34.7	17.3	661	27.6	1.35
	Cereal	18	244	222.6	22.8	13.8	520	24.7	0.66
	Shrubs	31	275	70.1	17.0	22.1	375	9.4	0.54
	Grassland	11	142	180.8	22.9	15.6	564	16.9	0.42
	Forest	4	46	65.0	13.8	19.9	334	8.6	0.15
	Orchard	1	18	30.0	10.0	19.0	467	0.7	0.05
	Total/Mean	113	1382	281.2	21.7	18.7	500	39.8	7.87
Other	Vineyard	4	12	105.0	82.5	23.8	612	21.4	24.96
	Bare soil	31	317	21.7	10.1	14.4	760	93.2	17.30
	Maize	6	27	38.1	12.9	9.9	676	63.7	13.95
	Spring crop[a]	13	62	375.8	43.4	11.0	749	16.1	10.64
	Cereal	18	91	3059.9	52.6	11.6	739	11.6	3.53
	Maize + cover	3	21	21.2	10.9	8.7	560	19.9	2.65
	Arable crops	6	139	16.0	8.0	10.8	862	42.2	0.53
	Barley + cover	1	3	66.3	22.1	10.0	665	—	0.28
	Shrubs	3	8	16.0	8.0	—	780	10.8	0.13
	Vineyard + grass	3	6	105.0	76.7	24.3	608	1.0	0.02
	Grassland	5	89	176.7	50.4	16.3	751	0.7	0.01
	Forest	2	5	16.0	8.0	—	780	0.7	0.003
	Total/Mean	95	780	691.8	30.1	13.4	738	43.0	9.83
Grand total		208	2162	466	25.7	16.4	609	41.0	8.76

[a]Except maize, maize + cover and barley + cover classes.

against 3.5 t ha^{-1} yr^{-1} for cereals in the rest of Europe) is the high rock fragment content found in the MZ soils (e.g. Poesen and Lavee, 1994; Puigdefabregas *et al.*, 1996). The influence of surface stoniness on the decrease of sheet and rill erosion rates is described in many studies (see, for example, the references for Spain in Table 2.4.1) and percentage stone covers of 30–50% are regularly observed. Rates are also higher in the MZ for permanent cover such as grasslands, forests or shrubs, which can probably be related to differences in vegetation density for these land uses in the two zones, natural or perennial vegetation being less dense and with species having lower leaf cover in the MZ.

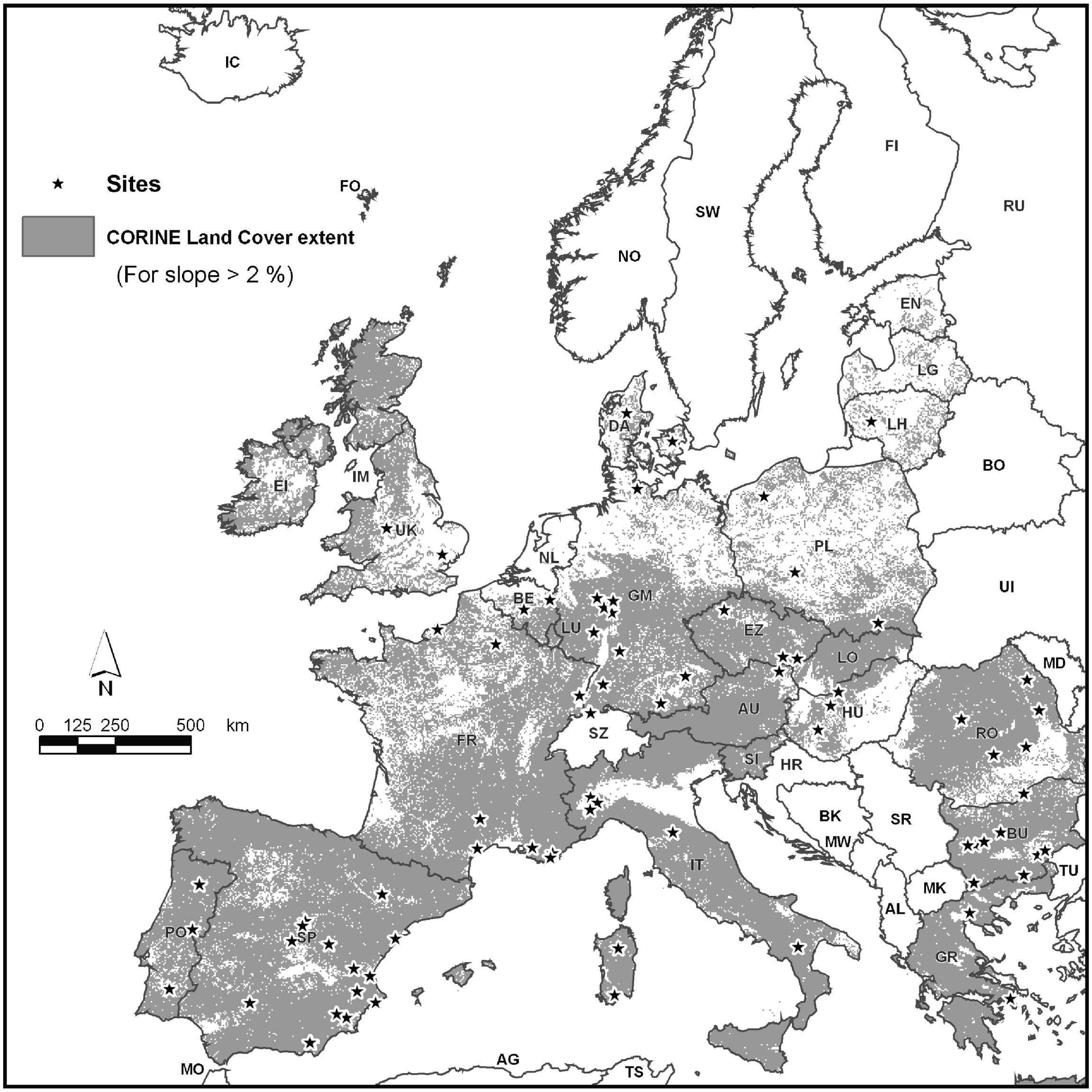

Figure 2.4.3 Extent of the reclassified CORINE land cover classes used in this study (areas with slopes below 2 % or outside the CORINE extent are represented in white)

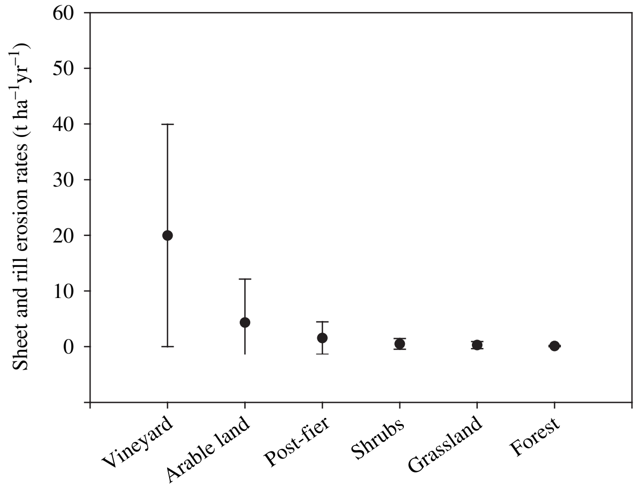

Figure 2.4.4 Mean (± SD) sheet and rill erosion rates aggregated per land uses present in the reclassified CORINE land cover classes

2.4.3.2 Extrapolation of Experimental Data to Europe

Mean sheet and rill erosion rates differ significantly according to land use. It is therefore interesting to calculate the spatial extent of the different land uses to assess sheet and rill erosion rates for Europe. Land cover can be estimated for Europe from the CORINE database. To homogenise the land use classes between the CORINE database and the soil loss database, both databases were reclassified. Figure 2.4.3 presents the extent of the reclassified CORINE land cover classes used in this study (the area where the slopes are <2 % are omitted as corresponding soil losses are usually very small) and Figure 2.4.4 and Table 2.4.4 present the soil loss database aggregated according to the reclassified CORINE land covers. Table 2.4.5 presents the potential mean sheet and rill erosion per land use according to its extent and erosion rate.

It is interesting that arable lands produce ~70 % of total soil loss. The mean calculated sheet and rill erosion rates for Europe are ~1 t ha^{-1} yr^{-1} for the total area and ~1.6 t ha^{-1} yr^{-1} for the erodible areas (i.e. in Table 2.4.4,

TABLE 2.4.4 Description of the soil erosion database aggregated according to the reclassified CORINE land covers

Land use	No. of entries	Equivalent plot-year	Mean area (m^2)	Mean slope length (m)	Mean slope (%)	Mean rainfall (mm yr^{-1})	Mean runoff (mm yr^{-1})	Mean erosion (t ha^{-1} yr^{-1})
Bare soil	54	563	60	14.4	15.9	674	91.7	23.40
Vineyard	10	113	100	52.3	19.3	629	80.8	19.97
Arable land	74	779	931	32.6	12.4	674	25.9	4.34
Post-fire	8	112	1859	11.3	28.7	466	40.2	1.54
Vineyard + grass	5	12	102	62.7	24.0	598	17.1	0.78
Shrubs	34	283	65	16.2	22.1	411	9.5	0.50
Grassland	16	231	179	31.5	15.8	623	15.2	0.29
Forest	6	51	49	11.8	19.9	483	6.0	0.10
Orchard	1	18	30	10.0	19.0	467	0.7	0.05
Total/mean	208	2162	466	25.7	16.4	609	41.0	8.76

TABLE 2.4.5 Mean sheet and rill erosion amounts and rates[a] for the reclassified CORINE land covers

Land use	Area (10^4 ha)	Mean sheet and rill erosion rates (t $ha^{-1} yr^{-1}$)	Mean sheet and rill erosion (10^4 t yr^{-1})	Mean slope (area <2 % excluded)	Mean slope (%)
No soil	1410	0	0.0	21.7	13.9
Arable land	5515	4.337	23919	6.7	3.9
Rice fields	7	0	0.0	4.7	1.1
Vineyards	292	19.97	5832	9.4	7.5
Orchards	518	0.052	27	15.3	13.6
Complex cultivation	3617	0.502	1816	11.4	8.6
Forest	6498	0.1	650	20.6	15.8
Grassland	3212	0.289	928	15.6	10.6
Shrubs	2415	0.502	1212	23.1	21.1
Post-fire	22	1.541	35	20.8	20.3
Wetland	127	0	0.0	12.2	6.4
Slope <2 %	11351	0	0.0	<2	<2
Total	34983	—	34418		

[a]Mean erosion rate: for the total surface ca. 1 t ha^{-1} yr^{-1}, for the erodible areas 1.6 t ha^{-1} yr^{-1}s.

land uses with a sheet and rill erosion rate >0). These mean values are, however, not an indicator of the significance of soil erosion in Europe as they average out spatial variabilities. For arable land in general and more specifically for vineyards (~20 t ha^{-1} yr^{-1}) and spring crops (~12 t ha^{-1} yr^{-1}), the average rates are well above acceptable rates of soil erosion (i.e. rates of erosion exceed rates of soil production). From our calculations, it appears that at least 16.7% of the total area covered by CORINE suffers from significant soil erosion problems. These figures are only indicative and should not be taken as absolute values. Furthermore, in addition of the approximation related to the extrapolation of plot data, the mean sheet and rill erosion rates should be corrected for mean slope (Figure 2.4.5), particularly for arable land (12.4 % for the plot database against an estimated 6.7 % for CORINE).

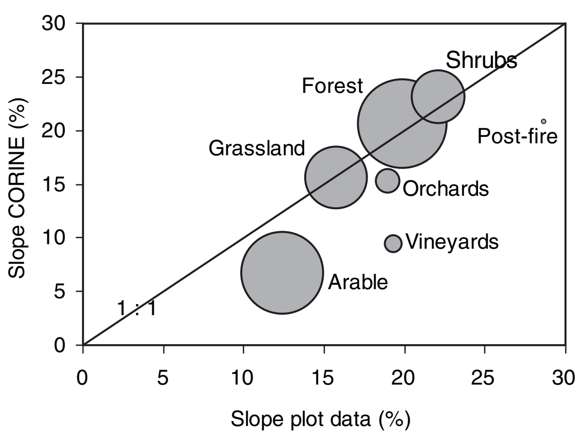

Figure 2.4.5 Mean slope of the reclassified CORINE land covers against the mean slope of the land uses present in the soil erosion database (circle size corresponds to relative area)

2.4.4 CONCLUSION

Sheet and rill erosion rates measured under different climatic, pedological, topographic and land cover conditions have been reviewed using an extensive database of short- to medium-term measurements at the plot scale from western and central Europe. The data confirm the important impact of land use on soil erosion rates. If we rank (in descending order) the land use classes according to the observed sheet and rill erosion rates, we obtain bare soil, vineyard, maize, spring crops, cereal, post-fire, forage, shrubs, grassland and forest. On the basis of these results, we calculated mean sheet and rill erosion rates for the total area in Europe, covered by CORINE ($\sim$1 t ha^{-1} yr^{-1}), and for the erodible areas ($\sim$1.6 t ha^{-1} yr^{-1}). However, from our calculations, it appears that arable land in general and more specifically vineyards ($\sim$20 t ha^{-1} yr^{-1}) and spring crops ($\sim$12 t ha^{-1} yr^{-1}), which represent 16.7 % of the total area covered by CORINE, suffer from significant soil erosion problems. These values should be treated with caution, given the difficulties encountered when extrapolating point measurements to regions. Nonetheless, they are based on measured soil loss values under natural rainfall and indicate an average soil loss below the previous published value of 17 t ha^{-1} yr^{-1} for Europe (e.g. Pimentel *et al.*, 1995).

REFERENCES

Andreu V, Forteza J, Rubio JL, Cerni R. 1994. Nutrient losses in relation to vegetation cover on automated field plots. In *Conserving Soil Resources, European Perspectives*, Rickson RJ (ed.). CAB International, Wallingford; 116–126.

Andreu V, Rubio JL, Gimeno-Garcia E, Llinares JV. 1998a. Testing three Mediterranean shrub species in runoff reduction and sediment transport. *Soil and Tillage Research* **45**: 441–454.

Andreu V, Rubio JL, Cerni R. 1998b. Effect of Mediterranean shrub cover on water erosion (Valencia, Spain). *Journal of Soil and Water Conservation* **53**: 112–120.

Andreu V, Imeson AC, Rubio JL. 2001. Temporal changes in soil aggregate and water erosion after a wildfire in a Mediterranean pine forest. *Catena* **44**: 69–84.

Auerswald K. 1993. *Bodeneigenschaften und Bodenerosion – Wirkungswege bei unterschiedlichen Betrachtungsmaßstäben* [Soil properties and soil erosion – interaction at different scales]. Verlag Borntraeger, Berlin.

Basso F, Pisante M, Basso B. 2002. Soil erosion and land degradation. In *Mediterranean Desertification: a Mosaic of Processes and Responses*, Geeson NA, Brandt CJ, Thornes JB (eds). John Wiley & Sons, Ltd, Chichester; 347–359.

Bautista S. 1999. Regeneracion post-incendio de un pinar (*Pinus halepensis*, Miller) en ambiente semiarido. Erosion del suelo y medidas de conservacion a corto plazo. Tesis Doctoral, Universidad de Alicante.

Bautista S, Bellot J, Vallejo R. 1996. Mulching treatment for postfire soil conservation in a semiarid ecosystem. *Arid Soil Research and Rehabilitation* **10**: 235–242.

Bolline A. 1982. Etude et prévision de l'érosion des sols limoneux cultivés en Moyenne Belgique. Unpublished PhD Thesis, University of Liège.

Canton Y, Domingo F, Solé-Benet A, Puigdefabregas J. 2001. Hydrological response of a badlands system in semiarid Spain. *Journal of Hydrology* **252**: 65–84.

Caredda S, Porqueddu C, Sulas L, Solinas V, Bazzoni A. 1997. Analisi ambientale di sistemi cerealicolo-zootecnicinsardi: aspetti erosivi. Nota I. *Agricoltura Ricerca* **170**: 43–50.

Castillo VM, Martinez-Mena M, Albaladejo J. 1997. Runoff and soil loss response to vegetation removal in a semiarid environment. *Soil Science Society of America Journal* **61**: 1116–1121.

Cerdà A. 2001. *Erosion Hydrica del Suelo en el Terrotorio Valenciano. El Estado de la Cuestion a Traves de la Revision Bibliografica*. Geoforma Ediciones, Logroño.

Cerdan O, Le Bissonnais Y, Souchère V, Martin P, Lecomte V. 2002. Sediment concentration in interrill flow: interactions between soil surface conditions, vegetation and rainfall. *Earth Surface Processes and Landforms* **27**: 193–205.

Clauzon G, Vaudour J. 1971. Ruissellement, transports solides et transports en solution sur un versant aux environs d'Aix-en-Provence. *Revue de Géographie Physique et de Géologie Dynamique* **13**: 489–504.

Diamantopoulos J, Pantis J, Sgardelis S, Iatrou G, Pirintsos S, Papatheodorou E, Dalaka A, Stamou GP, Cameraat LH, Kosmas C. 1996. The Petralona and Hortiatis field sites (Thessaloniki, Greece). In *Mediterranean Desertification and Land Use*, Brandt CJ, Thornes JB (eds). John Wiley & Sons, Ltd, Chichester; 229–245.

Dikau R. 1986. *Experimentelle Untersuchungen zu Oberflächenabfluß* und Bodenabtrag von Meßparzellen und landwirtschaftlichen Nutzflächen. Heidelberger Geographische Arbeiten, 81, Heidelberg.

Emde K. 1992. *Experimentelle Untersuchungen zu Oberflächenabfluß und Bodenaustrag in Verbindung mit Starkregen bei verschiedenen Bewirtschaftungssystemen in Weinbergsarealen des oberen Rheingaus* [Experimental analysis of runoff and soil delivery associated with rainstorms under different cultivation systems in vineyard areas of the upper Rheingau]. Geisenheimer Berichte 12.

Figueiredo T, Poesen J, Gonçalves-Ferreira A. 1998. The relative importance of low frequency erosion events: results from erosion plots under vineyards in the Douro region, northeast portugal. In *Proceedings of the 16th World Congress of Soil Science*, 20–26 August 1998, Symposium 31, Montpellier.

Francia JR, Ruiz-Gutiérrez S, Cárceles B, Martinez Raya A. 2002. Evolution of the runoff coefficients and the soil loss for different harvest intensities of the species *Lavandula tanata* and *Origanum bastetanum*. In *Sustainable Use and Management of Soils in Arid and Semiarid Regions*. Vol. II. Proceedings of the International Symposium on Sustainable Use and Management of Soils in Arid and Semiarid Regions, Faz Cano A, Ortiz Silla R, Mermut AR (eds). Cartagena, Murcia, 22–26 September 2002. Quaderna Editorial, Murcia.

Fullen MA. 1991. A comparison of runoff and erosion rates on bare and grassed loamy sand soils. *Soil Use and Management* **7**: 136–139.

Fullen MA. 1992. Erosion rates on bare loamy sand soils in east Shropshire, UK. *Soil Use and Management* **8**: 157–162.

Fullen MA, Reed AH. 1986. Rainfall, runoff and erosion on bare arable soils in east Shropshire, England. *Earth Surface Processes and Landforms* **11**: 413–425

Goeck J. 1989. Untersuchungen zur Wassererosion im Silomaisanbau mit und ohne Untersaat (Weißklee) bei variierten Saatterminen unter Berücksichtigung der Ertragsleistung [Experiments about water erosion in silage maize with and without intercropping (white clover) and with varying sowing dates]. Thesis Dissertation, University of Kiel.

Goeck J, Geisler G. 1989. Erosion control in maize fields in Schleswig-Holstein (F.R.G.). *Soil Technol. Series* **1**: 83–92.

Jankauskas B, Jankauskiene G. 2003. Erosion-preventive crop rotations for landscape ecological stability in upland regions of Lithuania. *Agriculture, Ecosystems and Environment* **95**: 129–142

Jung L, Brechtel R. 1980. Messung von Oberflächenabfluß und Bodenabtrag auf verschiedenen Böden der BRD [Measurement of runoff and soil loss on different soils of the FRG]. Parey, Hamburg.

Klik A, 2003. Einfluss unterschiedlicher Bodenbearbeitung auf Oberflachenabfluss, Bodenabtrag sowie Nahrstoff- und Pestizidaustrage. *Osterreichische Wasser- und Abfallwirtschaft* **55**:(5–6): 89–96.

Klik A, Zartl AS, Rosner J. 2001. Tillage effects on soil erosion, nutrient, and pesticide transport. In *Proceedings of the International Symposium Soil Erosion Research for the 21st Century*, Honolulu, Hawaii, January 2–5, 2001. American Society of Agricultural Engineers (ASAE); St. Joseph, MI; 71–74.

Kosmas CS, Moustakas N, Danalatos NG, Yassouglou N. 1996. The Spata field site: I. The impacts of land use and management on soil properties and erosion. II. The effect of reduced moisture on soil properties and wheat production. In *Mediterranean Desertification and Land Use,* Brandt CJ and Thornes JB (eds). John Wiley & Sons, Ltd, Chichester; 207–228.

Kwaad FJPM. 1991. Summer and winter regimes of runoff generation and soil erosion on cultivated loess soils (The Netherlands). *Earth Surface Processes and Landforms* **16**: 653–662.

Kwaad FJPM. 1994. Cropping systems of fodder maize to reduce erosion of cultivated loess soils. In *Conserving Soil Resources, European Perspectives,* Rickson, RJ (ed.). CAB International, Wallingford; 354–368.

Kwaad FJPM., Van der Zijp M, Van Dijk PM. 1998. Soil conservation and maize cropping systems on sloping loess soils in The Netherlands. *Soil and Tillage Research* **46**: 13–21.

La Roca N. 1984. La erosion por arroyada en una estacion experimental (Requena, Valencia). *Cuadernos de Investigacion Geografica* **10**: 85–98.

Le Bissonnais Y, Bruno J-F, Cerdan O, Couturier A, Elyakime B, Fox D, Lebrun P, Martin P, Morschel J, Papy F, Souchère V. 2003. Ma1trise de l'érosion hydrique des sols cultivés: phénomènes physiques et dispositifs d'action. *Programme GESSOL*, *Rapport Final*, March 2003.

Le Bissonnais Y, Lecomte V, Cerdan O. Grass strip effects on runoff and soil loss. *Agronomie* **24**: 129–136.

Lopes PMS, Cortez N, Goulao JNP. 2002. Rainfall erosion in Cambisols from Central Portugal. Some statistical differences between wet and dry years. In *Proceedings of the Third International Congress Man and Soil at the Third Millennium*, Rubio JL, Morgan RPC, Asins S, Andreu V (eds). Geoforma Ediciones, Logroño; 1291–1299.

Lopez-Bermudez F, Romero-Diaz A, Martinez-Fernandez J, Martinez-Fernandez J, Alonso-Sarria F. 1991. Research project on Mediterranean erosion desertification and land use. Field site: El Ardal, Mula basin (Murcia Southeast Spain). State of the research. April 1991, University of Murcia, Murcia.

Lopez-Bermudez F, Romero-Diaz A, Martinez-Fernandez J, Martinez-Fernandez J. 1998. Vegetation and soil erosion under a semi-arid Mediterranean climate: a case study from Murcia (Spain). *Geomorphology* **24**: 51–58.

Martin C, Allée P, Béguin E, Kuzucuoglu C, Levant M. 1997. Mesure de l'érosion mécanique des sols après un incendie de forêt dans le massif des Maures. *Géomorphologie: Relief, Processus, Environnement* **2**: 131–142.

Martin W. 1988. Die Erodierbarkeit von Böden unter simulierten und natürlichen Regen und ihre Abhängigkeit von Bodeneigenschaften [The erodibility of soils under simulated and natural rains and its dependence on soil properties], Thesis Dissertation, TU München.

Messer T. 1980. Soil erosion measurements on experimental plots in Alsace vineyards (France). In *Assessment of Erosion*, De Boodt M, Gabriels D (eds). John Wiley & Sons, Ltd, Chichester; 455–462.

Nicolau JM, Bienes R, Guerrero-Campo J, Aroca JA, Gómez B, Espigares T. 2002. Runoff coefficient and soil erosion rates in croplands in a Medditerranean-continental region, in Central Spain. In *Proceedings of the Third International Congress Man and Soil at the Third Millennium*, Rubio JL, Morgan RPC, Asins S, Andreu V (eds). Geoforma Ediciones, Logroño; 1291–1299.

Padron PE, Vargas Chavez GE, Ortega Gonzales MJ. 1998. Preliminary data from erosion experimental plots on Andisols of Tenerife (Canary Islands). In *The Soil as a Strategic Resource: Degradation Processes and Conservation Measures*, Rodriguez A, Jiménez Mendoza CC, Tejedor Salguero ML (eds), Geoforma Ediciones, Logroño; 219–227.

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri L, Blair R. 1995. Environmental costs of soil erosion and conservation benefits. *Science* **267**: 1117–1123.

Poesen J, Lavee H. 1994. Rock fragments in topsoils: significance and processes. *Catena* **23**: 1–28.

Porqueddu C, Roggero PP. 1994. Effetto delle tecniche agronomiche di intensificazione foraggera sui fenomeni erosivi dei terreni in pendio in ambiente mediterraneo. *Rivivsta di Agronomia* **28**: 364–370.

Puigdefabregas J, Alonso JM, Delgado L, Domingo F, Cueto M, Gutierrez L, Lazaro R, Nicolau JM, Sanchez G, Sole A, Vidal S. 1996. The Rambla Honda field site: interactions of soil and vegetation along a catena in semi-arid Southeast Spain. In *Mediterranean Desertification and Land Use*, Brandt CJ, Thornes JB (eds). John Wiley & Sons, Ltd, Chichester; 137–168.

Quinton JN. 1994. The validation of physically based erosion models – with particular reference to EUROSEM. Unpublished PhD Thesis, University of Cranfield.

Rivoira G, Roggero PP, Bullitta S. 1989. Influenza delle tecniche di miglioramento dei pascoli sui fenomeni erosivi dei terreni in pendio. *Rivista di Agronomia* **23**: 372–377.

Romero-Diaz A, Cammeraat LH, Vacca A, Kosmas C. 1999. Soil erosion at three experimental sites in the Mediterranean. *Earth Surface Processes and Landforms* **24**: 1243–1256.

Roxo MJ, Cortesao Casimiro P, Soeiro de Brito R. 1996. Inner lower Alentejo Field site: cereal cropping, soil degradation and desertification. In *Mediterranean Desertification and Land Use*, Brandt CJ, JB Thornes (eds). John Wiley & Sons, Ltd, Chichester; 112–228.

Schmidt RG. 1979. Probleme der Erfassung und Quantifizierung von Ausmass und Prozessen der aktuellen Bodenerosion (Abspülung) auf Ackerflächen. Physiogeographica, University of Basel.

Sirvent J, Desir G, Gutierrez M, Sancho C, Benito G. 1997. Erosion rates in badland areas recorded by collectors, erosion pins and profilometer techniques (Ebro Basin, NE-Spain). *Geomorphology* **18**: 61–75.

Tropeano D. 1983. Soil erosion on vineyards in the Tertiary piedmontese basin (northwestern Italy). *Catena Supplement* **4**: 115–127.

Vacca A, Loddo S, Ollesch G, Puddu R, Serra G, Tomasi D, Aru A. 2000. Measurement of runoff and soil erosion in three areas under different land use in Sardinia (Italy). *Catena* **40**: 69–90.

Viguier JM. 1993. Mesure et modélisation de l'érosion pluviale. Application au vignoble de Vidauban (Var). Unpublished PhD Thesis, University of Aix-Marseille.

Voss W. 1978. Ermittlung der Nährstoffumlagerung durch Erosion und Charakterisierung der Erosionsfracht einiger Vorfluter in hessischen Mittelgebirgs-Kleinlandschaften [Determination of the nutrient dislocation by erosion and characterization of the sediment load of some streams in mountain-ridge garden landscapes in Hesse]. Thesis Dissertation, University of Gießen.

Zanchi C. 1983. Influenza dell'azione battente della pioggia e del ruscellamento nel processo erosivo e variazioni dell'erdibilita del suelo nei diversi periodi stagionali. *Annali dell' Istituto Sperimentali perla Studio e Difesa Sueolo* **14**: 347–358.

Zanchi C. 1988. Soil loss and seasonal variation of erodibility in two soils with different texture in the Mugello valley in Central Italy. *Catena Supplement* **12**: 167–173.