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Assessment of soil erosion rates at the field and catchment scales in Galicia (Spain) from 1999 to 2004

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Résumé
La suivie systématique des pertes de sol sur des parcelles agricoles et des petites bassins versants élémentaires (environ 0.5 a 25 ha) cultivés a la province de La Corogne (Espagne) a permis de confirmer que a cette échelle là l'érosion diffuse et concentrée en rigoles et ravines temporaires est causée surtout par les pluies de printemps ou d'automne-début d'hiver sur des lits de semence ou des surfaces nues. La variabilité temporale de l'érosion a été très importante: absence d'érosion concentrée dans certaines campagnes, des intensités moyennes de l'ordre de 2 a 5 m^3/ha/an dans quelques autres et de l'ordre de 25 a 50 m^3/ha/an dans une saison avec des pluviométries exceptionnelles et quand la surface restait nue. A l'échelle de bassin versant agroforestier (36.3 km^2) le transport de solides en suspension a été faible, compris entre 0.05 et 5 t/ha/an. Il en résulte que la totalité des sédiments arrachés au niveau des parcelles n'arrive pas jusqu'au réseau hydrographique mais se dépose avant.

Introduction
In the agricultural environment of the autonomous community of Galicia (Spain), characterized by temperate Atlantic climatic conditions soil erosion rates are expected to be low to moderate in a global perspective. However, field observations over the last decade indicate that interill, rill and ephemeral gully soil erosion an important sediment source that can cause diffuse water pollution and eutrophication problems (Valcárcel, 1999; Taboada Castro, 2001; Valcárcel et al., 2003). Figures of sediments that may be delivered to streams are highly variable depending on physiographic and climatic factors and on human impact. Earlier investigations (Valcárcel, 1999, Valcárcel et al, 2003) had shown that in Galicia soil erosion mainly occurs when soil surface was poorly covered: tilled surfaces prepared for sowing maize in later spring and for sowing prairies and winter cereals in the autumn-early winter period. Erosion mean rates in a three year period were assessed at 2.67 m^3/ha/an. Erosion is very rare between July and October because both, water deficit and most fields are covered by crops; however even in this period local heavy rainstorms on bare soil may also cause important soil losses (Valcarcel et al., 2003).
The objective of this work was to investigate the delivery of sediment at two different scales, i) cultivated field or small catchment and ii) agroforestry catchment with a permanent stream and the delivery of eroded materials to aquatic environment in an area of Galicia with maritime climatic conditions.

Material and methods
The study was conducted at two different scales: agricultural field or small catchment (0.5 to 25 ha) and agroforestry catchment (36.3 ha) with a permanent water course. The investigation extended over six consecutive years, from January 1999 to December 2004. The two study areas were located near the town of La Coruña in contrasting geological and pedological conditions. The area has a maritime climate. Long-term mean annual precipitation ranges

between 1000 and 1100 mm. The rainy season extends from September-October to April-May in a normal year and in this period moderate to low intensity rains prevail. Summers are characterized by low total rainfall amounts leading to soil water deficits, but heavy storms may occur.

Cultivatedl field and small catchment scale

The study sites were located at the east of La Coruña in the Abegondo and Betanzos areas. Soils developed over basic schist are relatively deep for this region. Topsoil is silty loam and loan with high silt content (50-65%) and moderate clay contents (10-20%). Morphologically the study sites were hillslopes and small catchments. Each site was hierologically isolated by natural and man made border features, i. e. independent source areas with regard to surface runoff. Field surveys were made yearly at least in two different seasons: late spring and autumn-early winter. Rill and gully systems were detailed mapped when concentrated erosion was observed and sediment production was quantitatively evaluated by measuring channel volume. The volumes of sediment were divided by the area of the elemental hydrologic unit, hillslope or catchment, to obtain an area volume, m^3/ha. Moreover, semiquantitative and qualitative observations were made on surface roughness, evidence of overland flow, sheet erosion, ponding, tillage and tillage erosion, etc. Detailed topographical maps also were elaborated for each study site.

Agroforestry catchment scale

The study was realized in the Valiñas River located south of La Coruña. The experimental catchment area was 36.3 km^2 and a permanent stream drained it. Soil use includes about 45% forest, 35 % cropland and 20 % pasture. Agricultural landscape is very fragmented and still typical for traditional farming and livestock raising activities. The rock underneath in most of the study area is granite and some schist outcrops are also present. Soils are mainly loamy-sand and loamy with and the topsoil is rich in organic matter. A total of 720 samples were taken during the six study years. The smallest yearly set of samples collected was 53 in 1999 and the highest was 193 in 2003. Suspended solids were determined after filtration using a 0.45 m pore filter. Water discharge at the catchment outlet was measured different times along the study years in conditions of base and peak flow. Daily data of discharge were obtained by modeling after calibration with the experimental measurements (Sande Fouz, 2005). Soil losses from the catchment were calculated as the product of suspended solids concentration and discharge.

Results and discussion

Cultivated field and small catchment scale

At this scale and taken into account the whole investigation period there were important differences between the single campaigns. During autumn and winter 2000/2001 erosion intensities clearly were higher than in other campaigns. In contrast during the dry year 2004 concentrated erosion was reported only in two units in spring time, whereas in autumn-early winter surface channel incision was not observed. Sedimentary crusts developed from freshly tilled surfaces even during the driest spring and autumn periods from 1999 to 2004. Also evidences of overland flow and more or less generalized interril erosion were observed during all of the field survey campaigns. Regarding concentrate erosion the following situations could be roughly distinguished:

- No incision or limited rill incision, i. e., below 2 $m^3 ha^{-1}$ as for example in autumn 2004.
- Generalized rill and ephemeral gully incision in the class of mean values between 2 to 5 $m^3 ha^{-1}$. In this case the contribution of each unit is very variable, ranging from about 1 $m^3 ha^{-1}$ to 25 m^3 ha^{-1}. This was the most common erosion pattern during the study period and was illustrated for example by observations in spring and autumn 1999, autumn 2002, and spring 2003 and 2004.

- Heavy erosion was observed during an extremely winter period, between October 2000 and February 2002, with figures about ten orders of magnitude higher than before, thus between 20 and 50 m^3ha^{-1}. In a 6.26 ha hillslope the intensity of soil losses during this period were as high as 44.71 m^3ha^{-1} on bare soil and in a yearly basis soil losses in this site were in the order of 50 m^3ha^{-1}

Thus, low values of soil losses are dominant, but also large values of rill and ephemeral gully erosion occurred during the study period. This reflects mainly the effect of climate, but the occurrence and further development of rills and ephemeral gullies is multicausal, including climate, topography and human impact through crop rotation and tillage system. It is clear that concentrated erosion can cause transport of large amounts of swdiment to the water courses. These finding confirm previous results on the study area (Vlacárcel et al., 2003).

Agroforestry catchment scale

Summary statistics of suspended sediments and soil erosion at the Valiñas River catchment outlet during the period 1999-2004 is shown in Table 1. Mean annual values of suspended matter were between 13.67 and 91.12 mg/l in 2001 and 2002, respectively. There was a wide range of oscillation between minimum and maximum contents of the suspended matter. Mean yearly values Base flow suspended solid concentrations are negligible, < 1mg/l. During peak flow maximum recorded suspended solids contents varied between 99 and 1044 mg/l on a yearly basis. The annual number of samples containing suspended matter in excess of 100 mg/l was very limited, oscillating between 0 in 2001 and 12 in 2002.

Year	1999	2000	2001	2002	2003	2004
Rainfall (mm)	1253.0	1451.5	1115.9	1218.2	1200.3	786.1
Mean s. solids (mg/l)	30.15	30.9	13.67	91.12	23.93	17.32
Maximum s. solids (mg/l)	258	493	99	1044	399	207
Minimum s. solids (mg/l)	< 1	< 1	< 1	< 1	< 1	< 1
Soil losees (t/ha)	0.303	0.173	0.187	0.574	0.323	0.066

Table 1: Suspended soils concentrations and soil losses at the catchment outlet of the Valiñas River.

The yearly evolution of suspended solids content along 2000 and 2002 is shown in Figure 1. It can be appreciated that a few events of intense precipitation are responsible for the transport of suspended sediment and particles. In these periods sediments from different source areas, mainly uncovered soils and banks are mobilised. There is also a trend, as expected, to record maximum suspended solids contents in spring and autumn-early winter, whereas they tend to decrease the period between July and September.

Peaks of suspended sediment concentration occur at the beginning of each event and decrease before maximum water flow. This means that there is a hysteretic behaviour, so that suspended solids content tend to increase quickly at the beginning of each event and decreased before the peak of water discharge was reached. The absence of a linear relationship between discharge and suspended solids content makes difficult to evaluate the suspended matter losses.

Annual soil losses estimations were between 0.066 t/ha during 2004 the driest study year and 0.574 t/ha during 2002. Assuming that all the soil losses come from cultivated land (35% of the total area) and that grassland and forest land erosion is negligible, annual erosion figures would be of 0.49 t/ha in 2000, 0.53 t/ha in 2001, 1.64 t/ha in 2002 and 0.92 t/ha in 2003 and 0, 20 t/ha in 2004. However, field observations indicate that bank erosion may be significant in the study conditions. On the other hand, materials eroded by rill formations may be deposited before entering water courses. More research is needed to assess the spatial distribution of soil erosion and the relative importance f field concentrated erosion and bank erosion at this scale.

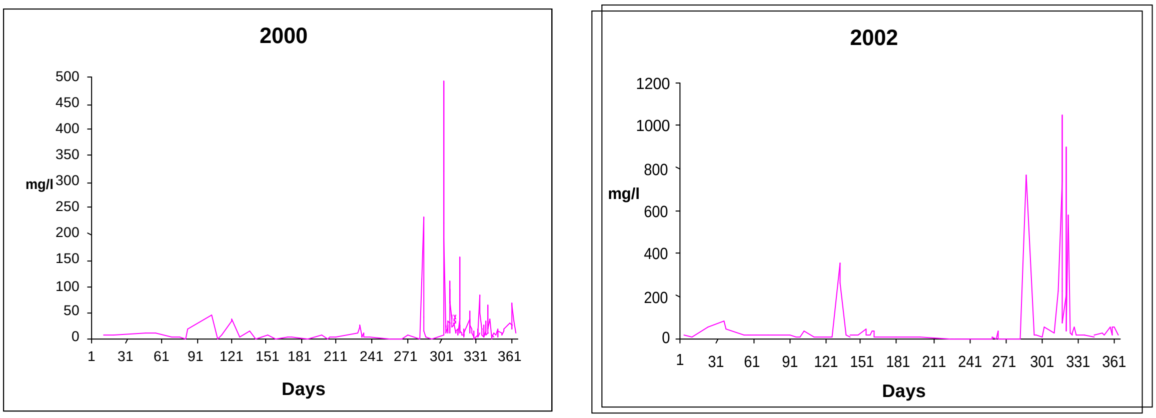

Figure 1: Annual evolution of suspend solids content during 2000 and 2002 year in Valiñas River catchment.

The above figures of suspended matter transport are low or moderate erosion and there is no concern for loss of soil fertility at the catchment scale. However a substantial proportion of nutrient causing stream eutrophication, mainly phosphorus, originate from the cultivated area (Sande Fouz, 2005). Thus, the delivery of fertilizers and pesticides with the eroded materials to the aquatic environment is the main concern in the study conditions.

Conclusions

In medium textured soils developed over basic schist rill and ephemeral gully erosion are common features. Substantial amounts of sediments may be delivered to streams, but figures are highly variable, depending on physical factors human impact. Yearly concentrated erosion rates currently are between 2 and 5 $m^3 ha^{-1}$, but in extremely rainy seasons, soil losses as high as 25 to 50 m^3 ha^{-1} were measured.
The delivery of suspended sediment from a mixed catchment with mainly granite bedrock and sized 36.3 km^2 was characterized by peaks of soil losses occurring at the beginning of each event, which decreased before the maximum of water discharge was reached. Yearly erosion rates from cultivated land and river banks varied between 0.066 and 0.574 t/ha^{-1}.

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