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Effect of Land Use on Soil Erosion in a Small Watershed of Emilia-Romagna Region

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ABSTRACT

BACKGROUND. The study of the environmental impact of soil erosion due to water runoff is important to protect soil quality and fertility. In order to estimate erosion at a watershed scale, discharge and sediment content in a stream draining a small watershed were studied.

METHODS. The Centonara watershed (197 ha), located in a hilly area South East of Bologna, Italy, has been monitored for water and suspended sediment discharge since 1994. Meteorological and hydrological data have been recorded continuously with the use of an ISCO flow meter and water samples have been collected from the stream in order to estimate transported sediment. Several thematic maps were produced (slope, pedological, geolithological, and morphological). In each agricultural season, the land use (tillage, crop, chemical treatment, fertilisation, etc.) was mapped (1:5000). Seasonal soil losses from the watershed, due to soil particles transported by water, were measured and related to the precipitation's characteristics and to the different agricultural soil use and management.

RESULTS. The results showed large yearly variability of the amount of transported sediment and a relation with the agronomic land use and management. In particular, the annual erosion of the watershed was related to the percentage of grass (meadows and set-aside) covered surface. The quantity of suspended and dissolved sediments and the electrical conductivity of water were found to be dependent on the season and the flow rate.

CONCLUSIONS. The high variability among years for rainfall, discharge and erosion quantities demonstrates the necessity of long term studies. A correlation between agricultural land use (represented by the percentage of soil covered by different crops) and soil losses was found. Salt concentration in discharge water had different seasonal trend with flow rate.

Key-words: watershed, discharge, erosion, land use, suspended & dissolved sediments

INTRODUCTION

Soil erosion reduces land productivity, challenges agricultural sustainability and degrades soil and water quality. Indirectly, soil erosion also degrades environmental quality through contaminants adsorbed to sediments. A substantial progress has been made over the past 50 years in understanding erosion and sediment transport and their effect on the environment. This understanding has led to the development and adoption of a wide variety of erosion control practices. Nevertheless, problems caused by erosion and sediment losses are still relevant and much remains to be studied. In hilly areas soil erosion is affected by many interrelated factors such as rainfall erosivity, slope, land use, soil, tillage and conservative practices. Traditionally, the cultivation of row crops on the hills of North-Central Italy was counterbalanced by careful water and soil management, such as interrupting the field slope by means of temporary ditches or spreading the runoff by ploughing downhill or at oblique angles to the contours (Giardini, 2002; Souchere et al., 1998; Takken et al., 2001a and 2001b), to reduce or avoid soil erosion, loss of soil fertility and water quality degradation. However the introduction of a simplified crop rotation, the longer slope and bigger extension of fields and the neglect of traditional water control measures resulted in an increase of soil erosion and water resources degradation. This kind of problems can be found in many parts of the world and numerous studies have been conducted on these topics. Many papers report solid loads and discharge for a variety of watersheds, along with information relating sediment loss to rainfall amount and intensity, runoff or land use (Osborne and Wiley, 1988; King, 1989; Hubbard et al., 1990; Soileou et al., 1994; Clausen et al., 1996). In this kind of studies most of the replications are not practically feasible, being difficult to find a watershed similar enough to be considered a replication, so that it is important to conduct several years lasting experiments. This allowed to evaluate the effect of land use changes on soil erosion regardless to meteorological variability between years.

The objectives of this study were:

i. To measure water discharge and soil loss from a hilly watershed of North-Central Italy, whose land use was monitored;
ii. To examine the relationships between rainfall, discharge, sediment losses and the land use variations in the 5 years under study;
iii. To study the differences of characteristics in transported solid, determining concentrations of dissolved and suspended solids and their relationships with the flow rate and the water electrical conductivity.

MATERIALS AND METHODS

Experimental Site Description

The present study was carried out in a small watershed (275 ha). The Centonara stream that drains the watershed waters is characterised by seasonal flow (the stream often shows no-flow periods during the summer). The experimental site is situated near Bologna (Italy, 44°25’ N, 11°28’ E) and has an altitude between 84 and 350 m a.s.l.. Several thematic maps of the whole watershed were produced during the initial phase of the study, namely pedological, geolithological, morphological, elevation and land use maps (Farabegoli et al., 1994). The average slope of the whole watershed was 28.2%, whereas the slope of the agricultural area, which represents 45% of the total, was 15.2%. A survey had been carried out every year in order to produce maps of the land use (1:5000) for each agricultural season and to have information about farming practices and chemicals (herbicides and fertilisers) applied. For practical reasons the measurement station was installed at an intermediate outlet point, reducing the measured catchment to 197 ha. All the following hydrological and land use data will refer to the reduced watershed. The land use of the investigated watershed is presented in Table 1. It is expressed as the percentage of the watershed characterised by a certain vegetation cover. Land use was relatively stable, because every year changes were restricted to the agricultural area, which is about 30% of the watershed. This area is cultivated mainly with winter wheat, barley, sorghum, sunflower, sugar beet, alfalfa and meadows.

Table 1. Soil use and extensions in the Centonara watershed.

LAND USE	Investigated sub-watershed SURFACES (ha)	%
Bushes	59.68	30.3
Woods	50.91	25.8
Natural vegetation	11.32	5.7
Cultivated	58.75	29.8
Rocks	14.10	7.1
Settlements	2.49	1.3
TOTAL	197.25	100.0

During the years of the study part of the cultivated area changed to set-aside (as indicated by the European Union in the Council Regulation 1251/99). Set aside leave the field uncultivated and cut once a year the herbaceous natural vegetation. The cut is usually done during May or June, depending on the seasonal conditions, and the cut weeds are left on the soil, to act as a mulch.

Table 2 shows the crops on the arable lands, during the studied period.

Monitoring and Sample Collection

A cross section (Figure 1) of the stream was modelled and a water flow measuring and sampling equipment was installed, in order to have water velocity and level continuously monitored. The velocity was measured by means of

Table 2. Land use: percentage of the cultivated land. Winter crops = wheat, barley. Spring crops = sorghum, sunflower, sugar beet. Grassland = alfalfa, meadows

Year	Winter crops (%)	Spring crops (%)	Grassland (%)	Set-aside (%)
1994/95	53,8	26,5	19,7	0,0
1995/96	38,8	36,4	23,9	0,9
1996/97	31,6	36,7	30,0	1,7
1998/99	33,6	8,7	33,2	24,5
1999/00	33,0	27,3	32,7	7,0

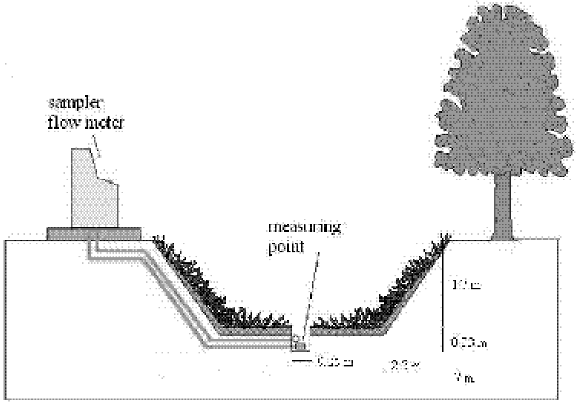

Figure 1. Centonara stream cross section and measuring equipment

a Doppler sensor, the level by means of a pressure sensor. The discharge rate was calculated as the product of water level multiplied by cross section area and by water speed.

From 1994 to 1998 the monitoring unit collected data at short time intervals, namely 2 minutes. The equipment needed to be replaced during the summer of 1998. With the new equipment data were collected with a 30 min time interval. In order to have homogeneous time interval data set from 1994 to 2000, all the flow rate and discharge data were re-calculated using the 30 min time interval. This resulted in an under-estimation of the flow rate, leading to discrepancies with data previously published (Gardi et al., 2000), mainly during high flow periods. The relationship between the 2 minutes and the 30 minutes discharge rate measurements resulted to be linear. The relationship between the monthly discharge rate (D_m) calculated with the two time steps was: $D_m(30') = 0.55\ D_m(2')$ with a $r^2 = 0.97^{***}$.

The technical problem with the first measurement equipment caused data discontinuity at the end of 1997 and during 1998. It was decided to simulate the missing data in 1997 (111 days) using the TOPKAPI model (Ciarapica and Todini, 1998). The model was previously calibrated in the same watershed (Rossi et al., 1998; Rossi Pisa et al., 1999), meteorological and soil use data were used for the simulation. The results were used to have a complete data series in the hydrological year 1996/97. The year 1997/98 lacked too many data (269 days) and it was decided not to consider it in the present work. The year 1998/99 has 180 days of data because the stream was dry for long periods, as confirmed by the low yearly precipitation amount (Tab. 3)

The sampling unit contained 24 one-litre bottles and collected one sample per day. Samples were analysed in order to measure sediment concentration (g L^{-1}) for particles with less than 2 mm size and, starting from 1997, electrical conductivity. In the first period sediment concentration was determined by oven drying the whole samples. From 1997 the samples were filtered to separate dissolved from suspended solids. Suspended sediment was determined as the oven-dry weight of the soil into the filter paper. Dissolved solids were determined by oven drying the filtrate. Total solids were the sum of the two fractions, suspended and dissolved sediments. In this way we measure the total amount of soil carried out from the watershed by the stream.

Meteorological data were automatically collected by a station situated in the watershed, at 200 m a.s.l. A continuous database starting from 1992 allowed the climatological characterisation of the area and a Bagnouls and

Table 3. Annual precipitation (P_y), discharge (D_y), discharge coefficient ($Dc_y=D_y/P_y$) and sediment loss (S_y). The number of available complete days of data per year is also showed. The average of the 5 years and the Coefficient of Variation (C.V., as a percentage) are also indicated. Please note that the year 1997/98 is missing, due to the lack of data.

	days of data (n.)	P_y (mm yr^{-1})	D_y (mm yr^{-1})	Dc_y	S_y (t ha^{-1} yr^{-1})
1994/95	310	793	126	0.16	15.9
1995/96	323	746	212	0.28	3.0
1996/97	355	800	368	0.46	7.8
1998/99	180	619	50	0.08	0.6
1999/00	322	709	241	0.34	5.2
Average		733	199	0.26	6.5
C.V. (%)		10	66	59	95

Gaussen graph was produced (Figure 2). The Centonara watershed area is characterised by two rainy periods, in spring and autumn, as shown in Figure 2. In the observed period the total annual rainfall ranged from 620 mm yr^{-1} to 800 mm yr^{-1} and averaged 733 mm yr^{-1}, just as the whole data-set (1992 – 2000, average =731 mm yr^{-1}).

In this research the year was regarded as starting from October 1 and ending on September 30 for all the meteorological, hydrological and agricultural variables considered, following the agricultural cycle. For each year the total and monthly rainfall (P_y and P_m), total and monthly discharge (D_y and D_m, calculated using instant readings of flux velocity, water level and the cross section area from the measurement station), sediment loss (S_y and S_m, calculated from daily discharge and sediment concentration) and discharge coefficient (Dc_y and Dc_m where Dc = D/P) were determined.

An extensive description of the trial can be found in Rossi Pisa et al., 1996a, and 1996b.

RESULTS AND DISCUSSION

Hydrological Data

Rainfall and discharge data showed quite high variations during the considered five years. Table 3 shows the annual data, the average of the 5 years and the Coefficient of Variation (C.V., as a percentage). The fraction of the annual rainfall flowing out of the basin (Dc_y) ranged from 0.08 to 0.46, the highest value occurring during the year with the largest amount of rain (1996/97). The mean value (0.26) was similar to those observed for watersheds with equivalent land use (Wu et al., 1983).

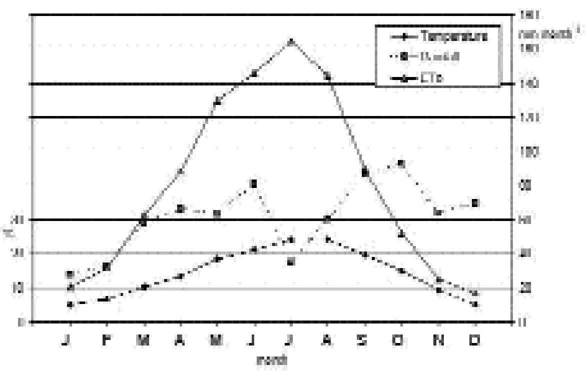

Figure 2. Climatological characterisation of the Centonara watershed using a Bagnouls and Gaussen graph. The evapotranspiration was estimated using the Hargreaves (1994) equation.

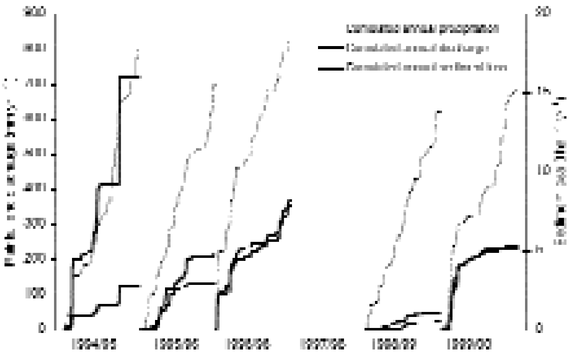

Figure 3. Annual cumulated precipitation, discharge and soil loss. Please note that the year 1997/98 is missing, due to the lack of data.

Annual soil loss per unit area (S_y) was found to be variable too, with higher losses occurring during rainy years. The relationship between annual precipitation on one side and discharge or sediment loss on the other was linear, with $r^2 = 0.81^*$ in the first case and $r^2 = 0.67^*$ in the second one.

Figure 3 shows these data as annual cumulated. The differences among years are more evident, mainly for sediment losses. Referring to the first year, it can be seen that a spring rainfall event (123.6 mm in two days, 23rd - 24th of June, 1995, with a maximum intensity of 6.4 mm in 10 min) resulted in 45 mm of discharge in two days, with a very heavy concentration of sediment (14.7 g L^{-1}). The total soil loss of the event, only from suspended sediments, was 6.6 t ha^{-1}, accounting for almost half of the annual sediment loss. The fact that one event can represent most of the year erosion is consistent with the findings of many researchers (Clausen et al., 1996, Schreiber et al., 2001, McBroom et al., 2003).

The same data were analysed on a monthly basis, both as the mean of the five years (Table 4) and as single data (Figure 4). Data in Table 4 show that the highest discharge coefficients were observed during the autumn and winter months, independently of the rainfall amount. This effect could be due to the smaller vegetation cover during the autumn and winter months compared to the other seasons and to a higher soil moisture resulting in less soil

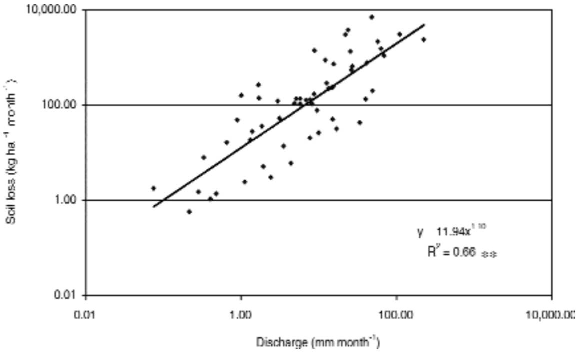

Figure 4. Measured monthly soil loss as a function of monthly discharge. Please note that the axes are logarithmic.

cracks. On the other hand, the highest sediment losses were registered during the months with the highest precipitation amount and intensity. The highest soil losses occurred in June, mainly accounted by the event described previously, and in November.

The relationship between monthly rainfall and discharge and between monthly discharge and cumulated soil loss was also investigated. In the first case a linear function best fitted the data ($D_m = 0.31\ P_m$, in mm month^{-1}, with $r^2 = 0.80$***). Soil losses monthly data (S_m) showed a non-linear relationship with D_m, with a high variation range, as shown in Figure 4 (r^2=0.66**).

Table 4 shows also monthly corrivation times (Tc_m) of the watershed. They range from 36 minutes to 48 hours, with an average of 10:59 (hh:mm) hours. The higher values are registered in April and October, when rainfalls are abundant and with low intensity, the minimum value of Tc_m is registered in August. The minimum corrivation time reached for increasing values of rainfall intensity in the watershed would be 9:33 hh:mm.

Impact of Land Use on Soil Erosion

The impact of the agricultural land use was analysed comparing variations of surfaces of winter crops, spring crops, grassland and set-aside among years and annual hydrological data, comparing data in Table 2 and Table 3.

The total sediment transported by the stream per year is shown as a function of the percentage of (grassland)+(set-aside) in Figure 5. Five years of data allowed us to calculate a curve (r^2=0.72) that can help us to estimate the amount of yearly transported soil, knowing the percentage of watershed covered all year around by herbaceous vegetation. This vegetation reduces soil erosion independently of the annual amount of precipitation. The same rela-

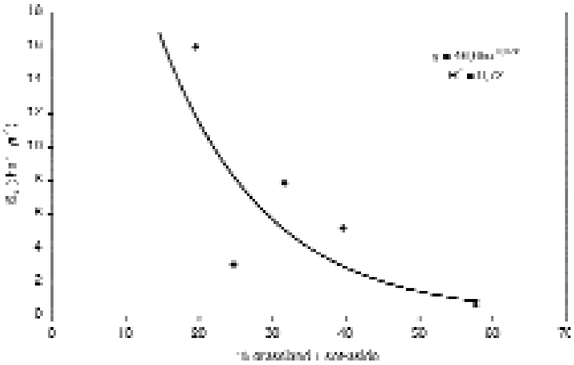

Figure 5. Annual sediment loss as a function of percentage of the watershed surface covered by grass and set aside.

Table 4. Mean monthly precipitation (P_m), discharge (D_m), discharge coefficient (Dc_m=D_m/P_m) sediment loss (S_m), maximum monthly corrivation time (Tc_m) during the study period (1994 - 2000)

	P_m (mm month^{-1})	D_m (mm month^{-1})	Dc_m	S_m (t ha^{-1} month^{-1})	Tc_m (hh:mm)
Jan	29	10	0.35	0.45	36:41
Feb	48	16	0.33	0.50	21:48
Mar	58	17	0.29	0.69	46:10
Apr	60	11	0.19	0.12	46:40
May	57	12	0.21	0.07	30:56
Jun	74	19	0.26	1.39	42:38
Jul	39	3	0.07	0.03	24:39
Aug	69	15	0.21	0.32	15:36
Sep	66	6	0.09	0.15	21:20
Oct	78	49	0.63	0.65	48:00
Nov	93	31	0.34	1.34	23:13
Dec	68	34	0.49	0.78	33:00

tionship is not evident with the runoff or the discharge coefficient. In the five-year study a lower percentage of spring crops in the watershed tended to reduce the discharge coefficient but the confirmation of this trend will be achieved only with the progress of the experiment. The same analysis considering S_y gave us worse results, due to S_y of the year 1994/95 much higher than the others. Having a larger number of data (years) will increase the data homogeneities, and the reliability of the results.

Dissolved and Suspended Sediments and Flow Rate

Starting from 1997 the collected samples were filtered to separate dissolved from suspended solids. Dissolved solids could be related to the presence of clay soils in badlands, such as calanchi (Farabegoli and Agostini, 2000), representing about 7% of the investigated watershed, on slopes ≥35% .

Dissolved salt concentrations, compared to suspended sediments, did not change much during the observed period (Figure 6), with values ranging from 1.0 to 2.5 g L^{-1} (Coefficient of Variation: dissolved = 32%, suspended = 223%). The few events with dissolved sediment concentrations greater than 2 g L^{-1} occurred in springtime (March to May). Suspended solids were more related to the rainfall characteristics (intensity and erosivity, the capacity of rainfall to remove soil particles and displace them, Beuselink et al., 2002). Suspended sediment showed very low concentrations in most of the data (between 0 and 1 g L^{-1}), with peaks mainly occurring during autumn high-discharge events.

The electrical conductivity measured in the filtered samples showed a different behaviour depending on the time of the year. Figure 7 shows the water electrical conductivity as a function of the flow rate. The data were divided into summer (June to September) and rest of the year, showing very different trends: summer data revealed that the conductivity was not much altered by the flow rate, having values of about 2 mS/cm, even with high fluxes; the rest of the year data pointed out a conductivity decreasing with the flux rate, due to a dilution effect. This result is probably due to a summer higher organic matter mineralization rate.

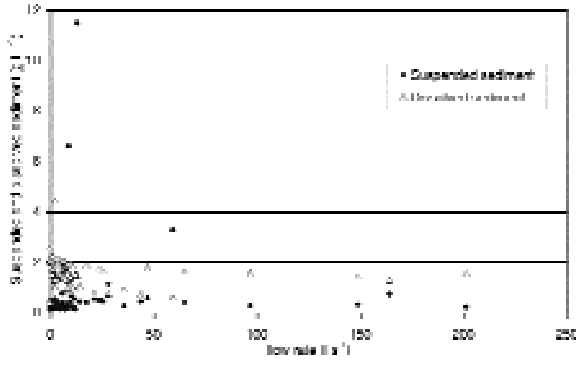

Figure 6. Suspended and dissolved sediment as a function of the flow rate.

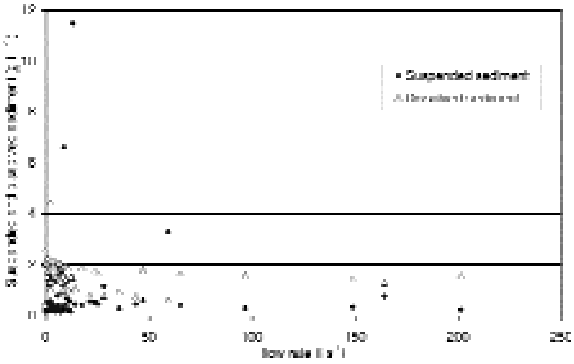

Figure 7. Electrical conductivity of filtered samples as a function of the flow rate. Data are divided in summer (June to September) and rest of the year.

This five-year experiment showed that:

- there was a high variability among years for rainfall amounts, discharge and soil losses, demonstrating the necessity of long term studies to give evidence for general trends;
- a single event could account for most of the annual sediment loss. Relationships between monthly rainfall, discharge and soil loss were found;
- there was a correlation between the agricultural land use (expressed as percentage of the land cultivated with different crops) and soil losses, underlining the importance of the differentiation of cropping systems in the watershed to reduce soil losses;
- dissolved sediment concentrations were nearly constant, as a function of the flow rate, during the observed period, with low variation compared to the suspended sediments. High concentrations of suspended sediment occurred in correspondence of autumn events, with low flow rate but high percentage of bare soil (27% of spring crops

that cause the soil exposed in autumn/winter);

- electrical conductivity had a different trend in summer (June to September) when the conductivity had constant values, whilst in the rest of the year it was lower and decreasing with the flow rate. This phenomenon was probably due to higher ions concentrations and higher organic matter mineralization during the dry season as an effect of lower soil water content.

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EFFETTO DELL'USO DEL SUOLO SULL'EROSIONE IN UN BACINO PEDECOLLINARE DELL'EMILIA-ROMAGNA

SCOPO. Lo studio dell'impatto ambientale dell'erosione del suolo dovuta a ruscellamento è importante per la salvaguardia della qualità e della fertilità del terreno. Al fine di valutare l'erosione a scala di bacino sono stati studiati il deflusso e il contenuto di sedimenti in un corso d'acqua drenante un piccolo bacino.
METODI. Il bacino (197 ha), sito in un'area collinare a Sud Est di Bologna, Italia, è drenato dal rio Centonara ed è soggetto a monitoraggio sin dal 1994. Dati meteorologici e idrologici sono stati registrati in continuo mediante un misuratore di portate ISCO, sono stati raccolti dal rio dei campioni di torbida al fine di stimare il trasporto dei sedimenti. Sono state realizzate diverse mappe tematiche (pedologica, geolitologica, morfologica e dell'acclività). Per ogni annata agraria è stato rilevato l'uso del suolo (colture, lavorazioni, fertilizzanti, trattamenti chimici) e sono state prodotte mappe a scala 1:5000. Nel presente lavoro sono state misurate le perdite stagionali di suolo dal bacino dovute al trasporto nell'acqua di particelle di terreno. Queste sono state correlate alle caratteristiche delle precipitazioni ed al differente uso e gestione del suolo.
RISULTATI. I risultati hanno evidenziato una notevole variabilità del quantitativo annuale di sedimenti trasportati e una relazione tra perdite di sedimenti e gestione agronomica del suolo. In particolare, l'erosione annuale nel bacino è stata correlata alla percentuale di terreno destinato a prato-pascolo e set-aside. E' stato inoltre riscontrato che la quantità dei sedimenti in sospensione e in soluzione e la conducibilità elettrica dell'acqua sono dipendenti dalla stagione e dalla portata.
CONCLUSIONI. La grande variabilità interannuale di pioggia e di trasporto liquido e solido dimostra la necessità di condurre studi a lungo termine. E' stata osservata una correlazione tra uso del suolo (espresso come percentuale del territorio coltivato con ciascuna coltura) a livello di bacino e perdite di suolo. La concentrazione di sali nell'acqua di deflusso ha mostrato un andamento dipendente dalla stagione.

Parole chiave: bacino, deflussi, erosione, uso del suolo, sedimenti sospesi & dissolti.