Land and Water Integrated Management in a Small Watershed: Hydrological and Chemical Results

Paola Rossi Pisa, Francesca Ventura

University of Bologna, Department of Agroenvironmental Science and Technology
Via F. Re, 6-40126, Bologna, Italy
E-mail: pisa@agrsci.unibo.it

Abstract: The study of environmental impact of soil erosion due to water runoff is very important to protect soil quality and fertility. In hilly areas soil erosion is affected by many interrelated factors such as rainfall distribution, land use, crop, soil, tillage and management. Traditionally, the cultivation of row crops in the hills of North-Central Italy was counterbalanced by conservative water and soil management, to reduce or avoid soil erosion with loss of soil fertility and water quality degradation. In order to estimate the phenomenon at a watershed scale, discharge and sediment content in a stream draining a small watershed were studied.

The watershed is located in a hilly area South East of Bologna, Italy (44°25′ N, 11°28′ E, altitude between 84 and 350 m a.s.l., mean slope 28 %, mean slope of the agricultural area 15 %) and has been monitored since 1994. Meteorological and hydrological data have been recorded continuously, water of the stream has been sampled in order to estimate sediment and Nitrogen concentrations. Several thematic maps of the area were produced (slope, pedological, geolithological, morphological). In each agricultural season the land use (tillage, crop, chemical treatment, fertilisation, etc.) was mapped (1:5000) interviewing the farmers.

This research studies the seasonal soil and N concentration from the watershed for a long time period. The results showed large variability of the amount of sediment among years and a correlation with the agronomic land use. The mean annual sediment loss was 8 t • ha^{-1} • y^{-1}. In particular the annual erosion of the watershed was related to the percentage of surface covered by grass. The agricultural land use adopted in the area under study resulted in low N losses (average value 5.2 kg • ha^{-1} • y^{-1}) compared with similar agro-ecosystems.
Keywords: watershed, discharge, erosion, land use, nitrogen

1 Introduction

Soil erosion reduces land productivity, challenges agricultural sustainability and degrades soil and water quality. Indirectly, soil erosion also degrades environmental quality through contaminants attached to the sediment. 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, but problems caused by erosion and sediment continue and much remains to be accomplished. In hilly areas soil erosion is affected by many interrelated factors such as land use, crop, soil, tillage and management. Traditionally, the cultivation of row crops in the hills of Northern-Central Italy was counterbalanced by careful water and soil management, to reduce or avoid soil erosion with loss of soil fertility and water quality degradation. However the introduction of simplified crop rotation and of the set-aside practice, the greater extension of fields and the neglect of traditional soil management practices resulted in an increase of soil erosion and in 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 in most cases replications are not practically feasible so it is important to have experiments lasting for several years, in order to evaluate land use changes independently of meteorological variability.

Nitrogen can cause problems with water quality. High N concentration value, even to a lower extent of those of P, lead to excessive eutrophication in water bodies (Sharpley *et al.*, 1994). Nitrogen exists in a variety of forms in water and with suspended mineral particles. In many regions there is still a limited information on the amounts in which nutrients are exported from agricultural catchments. These data are needed to model management options for the optimisation of water quality and the sustainability of the agro-ecosystem. Water quality may vary considerably between different watersheds (Nelson *et al*., 1996, Dodds *et al.*, 1996) and the reasons for this variability are largely unknown.

The objectives of this study were:

(1) To measure water discharge, soil and N losses from a North-Central Italy hilly watershed, the land use of which was also monitored;

(2) To examine relationships between rainfall, discharge rate, nitrate losses and land use changes during the years under study.

2 Materials and methods

2.1 Experimental site description

The present study was carried out in a small watershed (275 ha) drained by the Centonara stream, characterised by seasonal flow (the stream shows often no-flow periods during the summer). It is situated near Bologna (Italy, 44°25′ N, 11°28′ E) and has an altitude between 84 m and 350 m a.s.l.. Several thematic maps of the area were produced during the initial phase of the study, such as pedological, geolithological, morphological, elevation (DEM) and land use maps (Farabegoli *et al.*, 1994). The average slope of the whole watershed is 28.2%, whereas the slope of the agricultural area, which represents 45% of the total, is 15.2%. A farm survey has 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.

2.2 Monitoring and sample collection

A cross section 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 measurement station is situated at an intermediate outlet point, reducing the measured catchment to 197 ha. From 1992 to 1998 the monitoring unit collected level data with a short time interval, namely 2 minutes. The equipment was replaced at the end of 1998. With the new equipment data were collected with a 30 minutes time interval. In order to have homogeneous time interval data set from 1992 to 2001, all the flow rate and discharge data were re-calculated using the 30 minutes time interval. This resulted in an under-estimation of the flow rate, leading to discrepancies with data previously published (Gardi *et al.*, 2000), particularly during high flow periods. The relationship between the discharge rate measured with the two minutes and 30 minutes time steps resulted to be linear, with slope 0.55 and $r^2 = 0.94$.

Technical problems with the first measurement equipment resulted in data discontinuity in the 1997/1998 period. It was decided to simulate some of the missing data using the TOPKAPI model (Ciarapica and Todini, 1998), in order to have a whole season of data in the year 1996/1997. The model was previously calibrated in the same watershed (Rossi *et al.*, 1998; Rossi Pisa *et al.*, 1999). Nevertheless the years 1997/1998 and 1998/1999 had too many missing data and are not considered in the present work.

The automatic water sampling refrigerated unit contains 24 1l bottles and takes samples at flow proportional intervals. Samples are analysed in order to measure sediment concentration (g/l) for particles with less than 2 mm size and nitrate concentrations. Sediment concentration was determined by oven drying the samples. Nitrate concentration in water was determined by colorimetric method. Meteorological data were automatically collected in 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.

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

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

3 Results

The Centonara watershed area (as well as the Southern Po Valley where Bologna is located) is characterised by two rainy periods, in springtime and fall. The total annual rainfall in the observed period ranged from 500 mm/y to 800 mm/y. The average of the years studied in the present paper is 687 mm/y, slightly less than the average (708 mm/y) of the whole data-set (1992—2001).

3.1 Land use data

The land use of the watershed is presented in Table 1. Land use was relatively steady, because every year there were changes only in the agricultural area, which is about 44 % of the whole watershed. Considering only the monitored sub-watershed about 30 % is cultivated, mainly with winter wheat, barley, sorghum, sunflower, sugar beet, alfalfa and meadows (Table 2). The remaining area is mainly reforested.

Table 1 Soil use and extension in the Centonara watershed

Land use	Whole watershed		Investigated watershed	
	Surfaces (ha)	%	Surfaces (ha)	%
Bushes	59.68	21.7	59.68	30.30
Woods	59.89	21.8	50.91	25.80
Natural vegetation	11.38	4.1	11.32	5.70
Cultivated	120.84	43.9	58.75	29.80
Rocks	14.10	5.1	14.10	7.10
Settlements	6.76	2.7	2.49	1.30
Water bodies	2.49	0.9	-	—
TOTAL	275.14	100.0	197.25	100.0

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

year	Winter crops (%)	Spring crops (%)	Grass land (%)	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
1999/00	33.0	27.3	32.7	7.0
2000/01	36.9	11.1	49.4	3.7
Average	38.6	27.6	31.1	2.6

In some years part of the cultivated area changed to set-aside (as indicated by the European Union). Winter crops along the years changes from the highest value of 53.8% to an average stable value of about 35%, whilst there is an increasing trend of the surface of grassland.

3.2 Hydrological data

The annual amount of rainfall and discharge showed a high variability in the period of study (Table 3) and so did the related parameters as sediment loss and discharge coefficient. The fraction of the annual rainfall flowing out from the basin (Dc_y) ranges from 0.08 to 0.52, the highest values occurring during the years with the largest annual amount of rain (1996/97) or when the rainfall amount was high during winter when the soil is almost without vegetation. The mean value (0.35) is similar to these observed for watersheds with similar land use (Wu *et al.*, 1983). The annual sediment losses also shows high differences among years. In the first year, a spring rainfall event (123.6 mm in two days with a maximum intensity of 6.4 mm in 10 min) resulted in 45 mm of discharge with a very heavy concentration of sediment (14.7 g/l). The total soil loss of the event was 6.6 t • ha^{-1}, accounting for almost half of the annual sediment loss. The fact that one event sometimes represents most of the year erosion is consistent with findings of many researchers, as underlined by Clausen *et al.* (1996) and Schreiber *et al.* (2001).

Table 3 Annual precipitation (P_y), discharge (D_y), discharge coefficient (Dc_y), sediment loss (S_y) and N loss (N_y). The number of available complete days of data per year is also showed

	days of data	P_y (mm • y–1)	D_y (mm • y^{-1})	Dc_y	S_y (t • ha^{-1} • y^{-1})	N_y (kg • ha^{-1} • y^{-1})
1994/95	310	793	126	0.16	15.9	3.7
1995/96	323	746	212	0.28	3.0	3.7
1996/97	355	800	368	0.46	7.8	9.5
1997/98	182	498	—	—	—	—
1998/99	180	619	—	—	—	—
1999/00	322	709	241	0.34	5.2	4.8
2000/01	343	642	337	0.52	8.5	4.3
Average		687	257	0.35	8.08	5.2

The relationships between monthly rainfall and discharge and between discharge and total monthly soil losses were investigated. In the first case the data were fitted by a quadratic function ($D_m = 0.004P_m^2 - 0.187\ P_m, + 10.79$ in mm/month, with $r^2 = 0.54$). The discharge and soil losses monthly data were log-transformed, because both quantities showed high variation ranges. In this way data showed a linear relationship (Fig. 1).

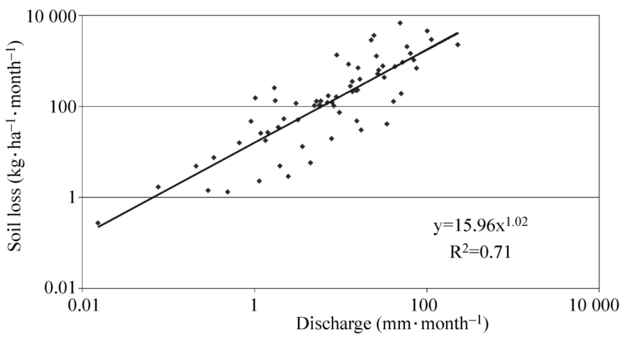

Fig. 1 Monthly soil loss as a function of monthly discharge. Note that the axes are logarithmic

3.3 Nitrogen losses

The water samples of the stream were analysed for the N content.

The chemical results are reported in Figure 2, where the trend of the monthly discharge and N losses per hectare are represented. These were calculated on the basis of the N concentration determined in each collected sample and multiplied by the total volume of water passed in the stream between two samplings. The graph shows the correlation between the two variables. The peaks of the N-losses were found mainly in spring (with concentrations between 20 g/l and 30 g/l) with the exception of the year 2000 when the peaks were in January (23.4 g/l), probably related to the cropping rotation of this year. The year 2001 showed low concentrations all along the year, with a peak of 9.5 g/l in February. The average nitrate concentration observed is 11.1 ppm considering the whole period. As total losses per year (Fig. 3) the mean value was 5.2 kg • y^{-1} • ha^{-1} and the maximum during the studied period was 9.5 kg • y^{-1} • ha^{-1}. These values are lower than the N-input due to the rainfall measured in the same area (Dinelli, personal communication). This fact enables us to conclude that the land use in the area is positive in order to prevent eutrophication of the water of the stream.

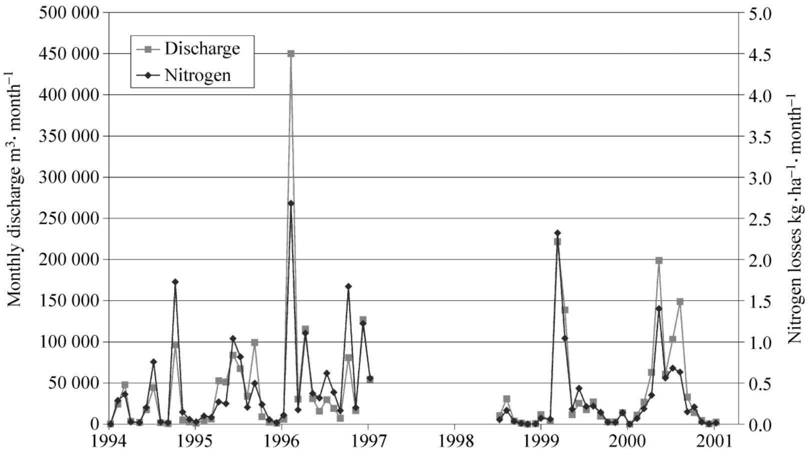

Fig. 2 Monthly discharge and Nitrogen losses in the watershed from Oct. 1st 1994 to Sep. 30th 2001

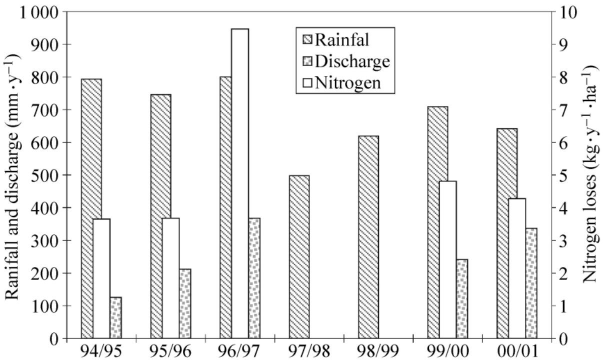

Fig. 3 Annual values of rainfall, discharge and nitrogen losses

3.4 Impact of land use on soil erosion and N losses

The annual soil eroded and N losses were analysed in relation to the land use (Table 1) and agricultural choices (Table 2). The land use of the catchment is almost stable during the years the only variations are within the cultivated area. For this reason only the agricultural land use was considered. Its impact was analysed comparing variations of surfaces of winter crops, spring crops, grassland and set-aside among years and annual hydrological data.

The soil loss by erosion was apparently correlated with the percentage of grassland area, independently of the annual rainfall amount.

Nitrogen losses were positively related to the amount of rainfall (Fig. 4). The N values are considerably lower that those measured in the rainfall in the same area and lower that those detected in other researches in similar environments with more conservative agricultural land use, such as grassland in Swiss and German (Dodds *et al.*, 1996).

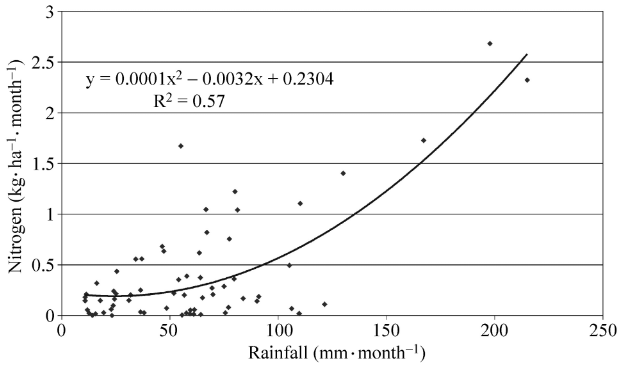

Fig. 4 Nitrogen losses related to monthly rainfall

4 Conclusions

This seven years long experiment in the watershed showed that:

- There was a high variability among years in rainfall amounts, discharge, soil and N losses. This underlines the necessity of long term studies to clarify general trends.
- The mean annual sediment loss was 8 t • ha^{-1} • y^{-1}, in one year a single event was responsible for most of the sediment lost.
- The soil and the N losses were found to be correlated with the discharge rate.
- The agricultural land use adopted in the area under study resulted in N losses lower than those reported in literature for European grassland ecosystem. This proves the importance of this kind of cropping systems for a sustainable agriculture.

As a general conclusion we can say that such findings may be useful in establishing our data as a baseline for N transport and soil losses in streams for similar agro-ecosystems.

Moreover, atmospheric N deposition data will bring a better knowledge of the N balance in the catchment.

References

Ciarapica L. and Todini E., 1998. Un modello afflussi – deflussi applicabile dalla scala di versante alla scala di bacino. Proceedings of XXVI Conv. di Idr. e Costr. Idr., Catania.

Clausen J.C., Jikela W.E., Potter III F.I. and Williams J.W., 1996. Paired watershed comparison of tillage effects on runoff, sediment and pesticide losses. J. Environ. Qual. **25**; 1000-1007.

Dodds W.K., Blair J.M., Henebry G.M., Koelliker J.K., Ramundo R. and Tate C.M., 1996. Nitrogen-transport from tallgrass praire watersheds. J. Environ. Qual., **25**, 973-981.

Farabegoli E., Rossi Pisa P., Costantini B. and Gardi C., (1994*).* Thematic maps for studying erosion at a basin scale (In Italian). Rivista di Agronomia n. **28**, 4, 371-383.

Gardi C., Vicari A., Campanini L. and Rossi Pisa P., 2000. Land use and water quality in a hilly watershed (in Italian). Riv. Agron. **34**, 364-372.

Hargreaves G.H., 1994. Defining and using reference evapotranspiration. J. Irr. Drain. Eng. **120**, 1132-1139.

Hubbard R.K., Sheridan J.M. and Marti L.R., 1990. Dissolved and suspended solids transport from coastal plain watershed. J. Environ. Qual., **19**, 413-420.

King J.G.,1989. Streamflow responses to road building and harvesting: a comparison with equivalent clear-cut area procedure. USDA-Forest Service, Research Paper INT-401, 1-13.

Nelson P.N., Cotsaris E. and Oades J.M., 1996. Nitrogen, phosphorus, and organic carbon in streams draining two grazed catchments. J. Environ. Qual., **25,** 1221-1229.

Osborne L.L. and Wiley M.J. 1988. Empirical relationship between land use/cover and stream water quality in an agricultural watershed. J. Environ. Manag., **26**, 9-27.

Rossi Pisa P., Gardi C. and Rossi M. (1996a*).* Continuous monitoring of soil erosion at field and watershed scale (In Italian). Quaderni di Idronomia Montana n. **15**, 281-300.

Rossi Pisa P., Vicari A., Gardi C. and Catizone P. (1996b). Use of a small watershed as a territorial case study (In Italian). Rivista di Agronomia n. **30**, 3 Suppl., 401-407.

Rossi Pisa P., Catizone P., Van Soetendael M., Ventura F. and Vicari A., 1999. Rilievi idrologici e vegetazionali di micrositi con finalità ambientali. Proceedings of *XXXIII* Convegno annuale della S.I.A., “Le colture non alimentari”, 20-23 Sept. 1999, Legnaro (PD), 325-326.

Rossi M., Van Soetendal M., Ciarapica L., Grasselli P., Rossi Pisa P. and Todini E., 1998. Comparison between TOPKAPI and Shetran model results after pre-processing and processing of digital elevation model data. Proceedings of 7th international Congress for Computer Technology in Agriculture “Computer Technology in Agriculture Management and Risk Prevention”, 15-18 November 1998, Firenze, a cura di CNR-IATA, pp. 128-129.

Schreiber J.D., Rebich R.A. and Cooper C.M., 2001. Dynamics of diffuse pollution from US Southern watersheds. Water Res., **35** (10) 2534-2542.

Sharpley A.N., Chapra S.C., Wedepohl R., Sims J.T., Daniel T.C. and Reddy K.R., 1994. Managing agricultural phosphorus for protection of surface waters: Issue and options. J. Environ. Qual., **23** 437-451.

Soileou J.M., Touchton J.T., Hajek B.F. and Yoo K.H., 1994. Sediment nitrogen and phosphorus runoff with conventional and conservation tillage cotton in a small watershed. J. Soil and Water Cons., **49**(1) 82-89.

Wu T.L., Correll D.L. and Remenapp H.E.H., 1983. Herbicide runoff from experimental watershed. J. Environ. Qual., **12**, 330-336.