EVALUATION OF THE EUROSEM MODEL FOR SIMULATING EROSION IN HILLY AREAS OF CENTRAL ITALY

VALUTAZIONE DEL MODELLO EUROSEM PER LA STIMA DELL'EROSIONE IN AREE COLLINARI DELL'ITALIA CENTRALE

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Abstract
Erosion is one of the main factors involved in soil degradation, affecting 5-6 million hectares of soil every year. The consequent loss of the most fertile portion of the soil and surface water pollution present high economic and environmental costs for the community.
Central Italy, because of its characteristic geomorphology and the current prevailing land use options, can be considered a vulnerable area to soil erosion. In fact, the prevalence of clayey soils and cropping systems based on durum wheat, frequently in rotation with sunflower and other spring-summer crops, implies bare soil for many months and exposes it to considerable erosion risk.
In the last 15 years, physically-based models have been developed to analyze processes related to erosion and to compare alternative land management options in order to minimize the vulnerability of agricultural lands. In this study, the simulation model EUROSEM has been calibrated and validated using data collected during a 3-year period, in a basin in the province of Ancona (Central Italy). Data collected in 1998 (bare soil) were used for calibration; data from 1999 (sunflower) and 2000 (winter wheat) for validation. Average (of all the elements) calibrated values of saturated hydraulic conductivity (FMIN), effective net capillary drive (G), detachability of soil particles (EROD) and soil cohesion (COH) were, respectively, 1.8 mm h^{-1}, 346 mm, 2.4 g J^{-1} and 10 kPa.
The model has been shown to effectively simulate runoff and erosion in the evaluated conditions: the modelling efficiency is positive for the entire examined period and the relative root mean square errors (RRMSEs) computed on the cumulated values of 13 events are lower than 80%, both for runoff and erosion. In fact, although there is some imprecision in the simulation of single events, observed and simulated means of all erosion data are similar (respectively 1.53 and 1.14 t ha^{-1}), so that the model has been proven adequate for scenario simulations and for alternative management comparisons.

Keywords: Runoff, USLE, saturated hydraulic conductivity, CropSyst, hypodermic runoff, small catchment basin.

Riassunto
L'erosione è uno dei fattori più importanti tra quelli implicati nella degradazione dei suoli; interessa infatti 5-6 milioni di ettari di suolo ogni anno. La conseguente perdita della frazione più fertile del terreno, unitamente all'inquinamento delle acque superficiali, presenta elevati costi ambientali ed economici per la collettività.
L'Italia centrale, per le caratteristiche condizioni geomorfologiche e climatiche e per l'attuale uso del suolo, può essere considerata una zona vulnerabile per l'erosione del suolo. Infatti, l'ampia diffusione di terreni con tessitura argillosa e di sistemi colturali basati sull'avvicendamento di colture autunno – vernine (es. frumento duro) con colture primaverili – estive (es. girasole) comporta la presenza di suolo nudo per diversi mesi, aumentando notevolmente il rischio di erosione.
Negli ultimi 15 anni sono stati sviluppati modelli di simulazione a base fisica per analizzare i fenomeni legati all'erosione e per confrontare alternative gestionali a bassa vulnerabilità. In questo studio, è stato calibrato e validato il modello di simulazione EUROSEM su dati raccolti, per un periodo di 3 anni, nel sottobacino "Spescia", a Serra de' Conti (AN). I dati raccolti nel 1998 (suolo nudo) sono stati utilizzati per la calibrazione, quelli raccolti nel 1999 (girasole) e 2000 (frumento) per la validazione.I valori calibrati (medi per tutti gli elementi) di conducibilità idraulica satura (FMIN), tensione al fronte d'inumidimento (G), erodibilità (EROD) e coesività (COH) sono, rispettivamente, 1.8 mm h^{-1}, 346 mm, 2.4 gJ^{-1} and 10 kPa.

Il modello, nelle condizioni esplorate in questa ricerca, si è dimostrato in grado di simulare adeguatamente il deflusso superficiale e l'erosione: l'efficienza di modellizzazione, calcolata su tutto il periodo, è positiva ed i valori di RRMSE sono, sia per il deflusso che per l'erosione, sempre inferiori all'80%. Infatti, nonostante alcune imprecisioni nella simulazione dei singoli eventi, le medie di tutti i valori di erosione osservati e simulati sono simili (rispettivamente 1.53 e 1.14 t ha^{-1}): il modello ha dimostrato di poter essere utilizzato per la simulazione di scenari e per la valutazione di alternative gestionali.

Parole chiave: *Deflusso superficiale, USLE, conducibilità idraulica satura, CropSyst, deflusso sottosuperficiale, piccolo bacino*

Introduction

The evolution of modern management techniques has led to important increases in crop yields over the past thirty years. In several cases, above all in vulnerable areas, this process results from the adoption of high impact agronomic practices. The current situation is characterized by an ongoing loss of natural habitats and widespread soil degradation (Pierce *et al*., 1984; Bazzoffi, 2002). Oldeman (1994) estimated that 562 million hectares of soil (about 38% of the 1.5 billion hectares in cropland worldwide) had been degraded, by 1990, because of high – impact agrotechniques.
One of the most important problems related to hilly agroecosystems is the soil erosion due to surface runoff. Kendall and Pimentel (1994) emphasized that the processes involved in soil degradation are extremely rapid compared with pedogenetic ones. In fact, they calculated that 200 – 1000 years are needed to produce a 2.5 cm deep soil layer. The following data confirm the significance of the problem: erosion is the main component of soil degradation (explaining 84% of it) and, in the case of intensive agricultural systems, it may interest more than 60% of cultivated soils (Bazzoffi, 2002).
Erosion leads to direct and indirect problems: (i) reduced productivity because of the loss of the most fertile portion of the soil (ii) reduced surface water quality through nutrient transport and the deposition of sediments in lakes, estuaries and riverbanks. Both these consequences present high economic costs for the society.
De Ploey *et al*. (1991) estimated that in Europe, 25 million soil hectares of land are affected by erosion. The Mediterranean area can be considered particularly susceptible to soil erosion by water because of the aggressive rainfall, the peculiar geomorphology and the socio – economic situation which has recently characterized rural lands.
The implementation of the Common Agricultural Policy (CAP) has led to an increase in rotations based on durum wheat, sunflower and other spring-summer crops, which have replaced the extensive traditional systems based on livestock and forage crops like alfalfa (Arzeni *et al*., 2000). Deep ploughing in summer is the current practice in most hill areas of Central Italy based on such cropping systems, because of the soil's clayey texture and the resulting difficulty of growing a summer crop through sod seeding. Therefore, most of the arable lands are kept bare between the wheat harvest (June – July) and summer crop establishment (March – May), when rainfall intensity can be far higher than the infiltration rate, particularly if the soil structure is degraded by heavy rain splash and low organic matter content. As the deep clayey soil layers are almost impermeable, soil saturation frequently leads to landslides, which are prevented on hill slopes by drainage ditches placed along the maximum slope.
The evaluation of the impact of alternative management practices on soil erosion in order to identify possible conservation strategies can be carried out using two different approaches: (i) direct erosion measurements comparing different cropping systems (Roggero and Toderi, 2002b) and (ii) use of simulation models to compare alternative scenarios (Bazzoffi, 2002). The first option is, above all for large scale evaluations, costly and time consuming (Sharpley *et al*., 1995; Bockstaller *et al*., 1997), while the second requires reliable and sensitive models to estimate the expected effects of changes in physical characteristics and management practices with sufficient precision. Reliable field data are essential to calibrate and validate soil erosion models, which are generally used to (i) estimate erosion in relation to already existing combinations of factors (land use, soil type and morphology, meteorological conditions); (ii) evaluate the impact of contrasting land uses on erosion and sedimentation; (iii) contribute to the planning of adequate conservation strategies; (iv) interpret the physical processes involved.
More generally, the application of simulation models to complex systems (e.g. agroecosystems) has contributed to a holistic representation of these systems and hence to facilitating the decision-making processes involved in the management of natural resources (Pala *et al*., 1996).
Several soil erosion simulation models have been developed, characterized by different levels of complexity. They may be grouped in three categories: empirical models such as the USLE (Wischmeier and Smith, 1965; 1978) with the related MUSLE (Williams, 1975) and RUSLE (Renard *et al*., 1987, 1991); process-based models like ANSWERS (Beasley *et al*., 1980) and CREAMS (Knisel, 1980), which still contain empirical aspects; physical models, such as WEPP (Lane and Nearing, 1989), KINEROS (Woolhiser *et al*., 1990) and EUROSEM (Morgan *et al*., 1995).
Empirical models are based on data collected in standard plots and this limits their applicability outside the range of situations they were derived from. Frequently, empirical models outputs are based on yearly reports, which are inadequate to study the dynamic evolution of the physical processes and for the theoretic analysis of phenom-

ena, which is a relevant aspect for large-scale application (Lørup and Styczen, 1996).
Process-based models take into account the laws of conservation of mass and energy. Moreover, they describe the spatial variation of erosion and sedimentation. Nevertheless, they are still partially based on empirical rules and, for this reason, they present a weak theoretical structure (Elliot *et al*., 1994).
Physically based models consider and reproduce the main factors influencing erosion, their spatial and temporal variability and describe the interactions between them. All these models refer to a hydrological model and to a system of equations which schematize the evolution of each process. In this way, they are able to provide a spatially and temporally distributed simulation of processes, independently of the context in which they were calibrated (Lørup and Styczen, 1996). However, to do so, they require a number of measured or estimated parameters, which are subject to errors and bias. American mod els (WEPP or CREAMS) are based on continuous simulations in which changes in soil conditions are simulated starting from daily water balance computation. For this reason, these models require ample meteorological and land use data. Often, such a quantity of data is not available and, moreover, in Europe almost all erosion is caused by two or three events per year (Morgan *et al*., 1998).
KINEROS and EUROSEM are physical – distributed models able to simulate the effect of several variables related to hydrology and the sediment distribution for each event. Compared with other erosion models, EUROSEM has explicit simulation of interill and rill flow. EUROSEM has been already used and tested, at the plot or small catchment scale, in many countries (Albaladejo *et al*., 1994; Sardo *et al*., 1994; Botterweg *et al*., 1998; Morgan *et al*., 1998; Jetten *et al*., 1999; Strauss *et al*., 1999; Veihe *et al*., 2001; Cai *et al*., 2005). It proved accurate in estimating total runoff and erosion, although in some cases the results of single-event simulations were not completely satisfactory.
This paper reports some of the results emerging from the calibration and validation of the EUROSEM model using three years of field data on water runoff, land use and agro-techniques. Data were collected in the "Spescia" micro-catchment in the hills of the province of Ancona by the Agronomy research of SAPROV Department, partially published by Roggero and Toderi (2002a). These data were used for (i) the calibration of EUROSEM in order to provide a useful tool for a quantitative evaluation of the impact of contrasting management strategies and for (ii) the evaluation of the technical adequacy of EUROSEM in relation to the peculiar environmental characteristics of the region.

Materials and methods

Experimental data

The Spescia microcatchment is located in the municipality of Serra de' Conti in the province of Ancona (Central Italy). It is managed by three farmers, but the durum wheat – sunflower rotation occupies almost all the arable land. The most important consequence of this kind of land use is that all the surface is bare in autumn. The pluviometric regime is characterized by about 1000 mm average rainfall per year, with a maximum during the autumn and a minimum in July. The main characteristic of the microcatchment are: total surface = 80.8 ha; arable land = 70.3 ha; length = 1.35 km; width = 1.09 km; average slope = 7%; maximum slope = 25% (Roggero and Toderi, 2002a).
The analysis of pedologic profiles evidenced the presence of sub-superficial unstructured clay layers which may favor hypodermic water flow.
Systematic samplings of runoff water started in 1998 to quantify suspended particles, nitrates and soluble phosphorous. An automatic device for runoff measurement was installed downstream from the main ditch, coupled to an ISCO Area Velocity Flow Meter (Teledyne Isco, Inc., Lincoln, Nebraska, USA). Three 500 ml (10 subsamples × 50 ml) samples are collected every 4000 m^3 of runoff (corresponding to about 5 mm runoff).
An automatic Campbell (Campbell Scientific Ltd., Logan, Utah, USA) weather station is installed near the basin and records hourly temperature, humidity and rainfall, while wind and radiation data were interpolated based on data collected by adjacent stations.
Figure 1 shows the position of the points where soil data where collected.Results of analysis are reported in Tab 1.
The microcatchment topography and DEM (digital elevation model) had been measured by the SAPROV research team and all spatial data have been reported in a Geographic Information System (GIS) (Roggero and Toderi, 2002a).

Simulation model

EUROSEM (Morgan *et al*., 1998) is a dynamic distributed model, linked to the KINEROS hydrological model (Woolhiser *et al*., 1990), able to simulate the evolution of each of the plots of a catchment during a single storm by adopting a user-defined time step (usually between 30 and 180 seconds). The model uses rainfall measurements during a storm to calculate rainfall intensity and rainfall volume. The "rainfall data file" records, for each storm, the cumulative rainfall as a series of time-depth pairs. During the simulation, rainfall is first intercepted by the plant canopy and then split into direct throughfall and leaf drainage, and stemflow. After determining the kinetic energy of these components, EUROSEM calculates soil splash detachment and models infiltration in accordance with the numerical approach of Smith and Parlange (1978). Runoff is then routed over the soil surface using the kinematic wave equation accompanied by the modeling of soil erosion as a continuous exchange of particles between the flow and the soil surface. Soil loss is computed as a sediment discharge, based on the dynamic mass balance equation. The main model outputs are total runoff, total soil loss, the storm hydrograph and storm sediment graph. An accurate description of the model is provided by Morgan *et al*. (1998).

Model parameterization and validation

EUROSEM simulates erosion by resolving the catchment into elements representing planes or channels. To get this representation of the catchment, contour lines were visualized on a map showing the actual land use and the catchment hydrography. In this way, possible abrupt changes in slope have been represented as a succession of planes in which the flow follows a cascade course. Successively, the DEM allowed a precise individuation of surface flow directions. In this way, the whole catchment surface has been divided into elements which are homogeneous for land use, hydrology and soil properties (Figures 2.a and 2.b).

The parameters describing soil hydraulic properties (soil water content at saturation [SWCs; m^3 m^{-3}], porosity [POR; m^3 m^{-3}], fraction of skeleton per soil volume [ROC; m^3 m^{-3}], saturated hydraulic conductivity [FMIN; mm h^{-1}], effective net capillary drive [G; mm] and Manning's number [n; $m^{1/6}$]) were set by using (i) direct measurement; (ii) pedotransfer function (using soil organic matter and texture data as input for the software SOILPAR 2.00; Acutis and Donatelli, 2003) or (iii) the values tabled in the EUROSEM user's manual.

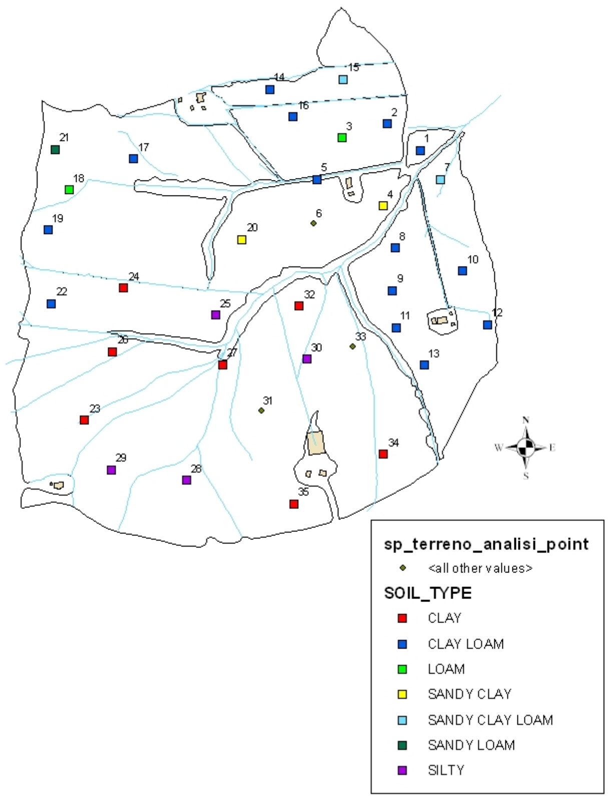


Fig. 1 - The Spescia catchment (Ancona Province, Central Italy). The squares indicate where soil analysis were carried out and their labels correspond to Table 1

Fig. 1 - *Il bacino Spescia (AN). I quadrati indicano i punti nei quali sono stati prelevati campioni di suolo per le analisi; i numeri in corrispondenza dei quadrati si riferiscono agli ID di Tabella 1*

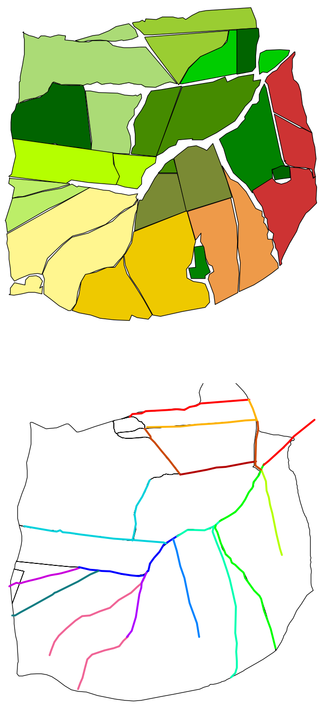


Fig. 2 - Resolution of the Spescia catchment into homogeneous elements. (a) planes; (b) channels

Fig. 2 - *Suddivisione del bacino Spescia in elementi omogenei. (a) piani; (b) canali*

Tab. 1 - Some results of the analysis carried out on the samples collected in the points evidenced in Figure 1. Spescia basin (Ancona Province, Central Italy)

Tab. 1 - *Alcuni dei risultati delle analisi dei campioni di suolo raccolti nei punti evidenziati in Figura 1. Bacino Spescia (Provincia di Ancona, Centro Italia)*

ID	sand (%)	silt (%)	clay (%)	organic matter (%)	soil type
1	40.5	30.0	29.5	1.5	C L
2	38.6	28.6	32.8	1.7	C L
3	44.4	28.2	27.4	1.0	L
4	49.5	24.4	26.1	1.5	Sa C
5	28.9	31.6	39.5	1.3	C L
7	46.7	23.9	29.4	1.3	Sa C L
8	44.4	26.3	29.3	1.6	C L
9	30.7	33.6	35.7	1.8	C L
10	34.6	31.0	34.4	1.5	C L
11	23.9	36.3	39.8	0.7	C L
12	33.7	31.5	34.8	1.6	C L
13	27.5	33.5	39.0	1.0	C L
14	41.4	29.3	29.3	0.6	C L
15	52.6	24.8	22.6	0.6	Sa C L
16	37.3	30.1	32.6	1.0	C L
17	38.7	27.9	33.4	1.3	C L
18	44.4	29.1	26.5	0.7	L
19	29.6	34.0	36.4	0.6	C L
20	50.7	24.8	24.5	0.9	Sa C
21	60.6	20.1	19.3	0.9	Sa L
22	29.7	33.8	36.5	0.9	C L
23	20.6	36.9	42.5	0.8	C
24	22.3	35.2	42.5	1.0	C
25	13.2	38.9	47.9	1.4	Si C
26	21.5	36.7	41.8	1.4	C
27	21.3	35.6	43.1	1.4	C
28	15.4	40.3	44.3	1.3	Si C
29	16.9	40.7	42.4	1.3	Si C
30	17.3	40.4	42.3	1.4	Si C
32	18.6	38.3	43.1	1.6	C
34	19.3	36.9	43.8	1.5	C
35	17.0	38.2	44.8	1.0	C

For each storm, the initial soil water content (SWCi; m^3 m^{-3}) was set by using the value simulated by CropSyst (Stöckle *et al*., 2003), parameterized for the situation which characterized the Spescia basin in the period 1998-2000. To parameterize the variation in time of the ratio of the straight line distance between two points on the ground to the actual distance measured over all the microtopographic irregularities (RFR), the indirect procedure (based on the kinetic energy of the raindrops) proposed by the user's manual was followed.
The parameters describing erodibility (measure of the soil particles detached by the splash effect [EROD; g J^{-1}] and soil cohesion [COH; kPa]) were set by using tabled values.
Parameters describing the canopy evolution through the season (e.g. proportion of soil covered by the vegetation [COVER; %], maximum water quantity intercepted by the vegetation [DINT; mm]) were set by combining information from (i) the tabled values for full-canopy stage and (ii) the leaf area index simulated by CropSyst with a daily time step. In this way, a dynamic representation of the canopy-related variables was obtained.
A two-steps sensitivity analysis was carried out to individuate the parameters with the higher influence on model outputs using data from the first measured storm, which occurred on 11 November 1998. During the first step, the parameters involved with runoff and erosion were varied (percentage variations within a range derived from the literature), for all the elements of the catchment. During the second step, the parameters with the higher influence (individuated in the first step) were co-varied and the simulated runoff was plotted in a diagram to identify the combinations producing maximum and minimum (Figure 5). This permitted the carrying out a kind of guided calibration. In fact, the model presented a remarkable underestimation both for runoff and erosion before the calibration. This procedure allowed researchers to begin the calibration by taking as the starting point the combination for which the model simulated appropriate erosion values.
Data from the storm events occurred in 1998 (four events) were used for calibration while the data from the other two years were used to validate the calibrated parameters. The correspondence between observed and predicted values was expressed by using the indices proposed by Loague and Green (1991) and recently reviewed by Martorana and Bellocchi (1999) and Donatelli *et al*. (2003): the relative root mean squared error (RRMSE, minimum and optimum=0%, equation [1]), the coefficient of determination (CD, minimum=0, optimum=1, indicates whether the model reproduces the trend of measured values or not, equation [2]), the modelling efficiency (EF, -∞ ÷ 1, optimum=1, if positive, indicates that the model is a better predictor than the average of measured values, equation [3]), the coefficient of residual mass (CRM, -∞-+∞, optimum=0, if positive indicates model underestimation, equation [4]) and the parameters of the linear regression equation between observed and predicted values.The equations of the indices are:

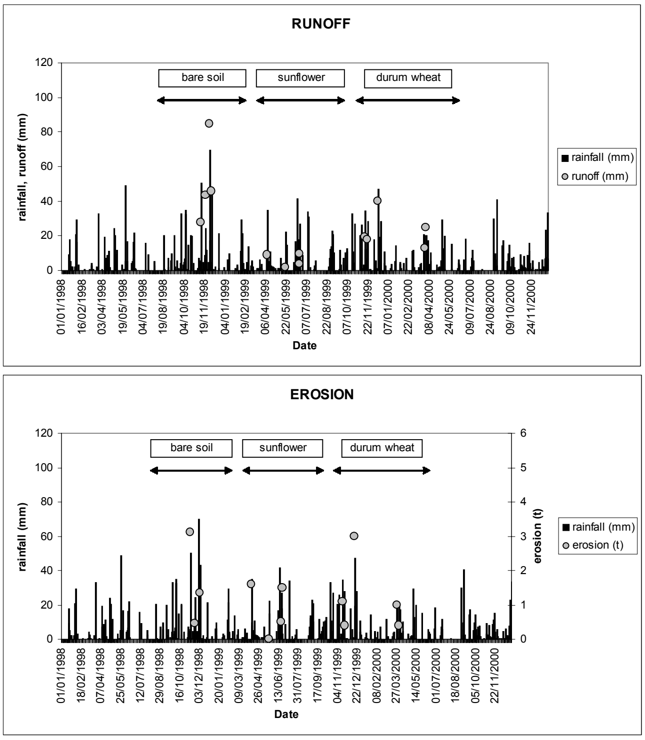


Fig. 4 - Measured (a) runoff and (b) erosion in relation to rainfall data for the period 1998 – 2000

Fig. 4 - *Valori misurati di (a) deflusso ed (b) erosione in relazione alle precipitazioni per il periodo 1998 – 2000*

$$RRMSE = \sqrt{\frac{\sum_{i=1}^{n}(Si-Oi)^2}{n}} \times \frac{100}{\overline{O}} \quad [1]$$

$$CD = \frac{\sum_{i=1}^{n}\left(S_i-\overline{O}\right)^2}{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2} \quad [2]$$

$$EF = \frac{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2-\sum_{i=1}^{n}\left(S_i-O_i\right)^2}{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2} \quad [3]$$

$$CRM = \frac{\sum_{i=1}^{n}O_i-\sum_{i=!}^{n}S_i}{\sum_{i=1}^{n}O_i} \quad [4]$$

where S_i are the simulated values; O_i are the observations; $\overline{O}$ is the average of observed values; n is the number of evaluated cases. The model's performance for each of the three years was also compared to the results obtained using the USLE approach (Wischmeier and Smith, 1965; 1978).

Results and discussion

Experimental results

In the monitored period, important storm events took place in the autumn of 1998 and 1999 and in June 1999. The year 2000 was characterized by drought during spring and summer and by light rainfall during the autumn. Details about runoff and erosion data in the Spescia basin during the studied period are discussed in depth by Roggero and Toderi (2002a). Figure 3 shows long term average rainfall data compared with data measured in the studied period. Figure 4 shows runoff (4.a) and erosion (4.b) in relation to rainfall data.

Model results

Calibration of the parameters involved in runoff

The first part of the sensitivity analysis (carried out varying the parameters one by one) resulted in the selection of FMIN and G as the parameters with the highest influence on runoff. The same two parameters had been already individuated by the other sensitivity analyses of EUROSEM (e.g. Veihe and Quinton, 2000; Veihe *et al*., 2000). Their combined effect (obtained by co-varying their values) on simulated runoff was then analyzed

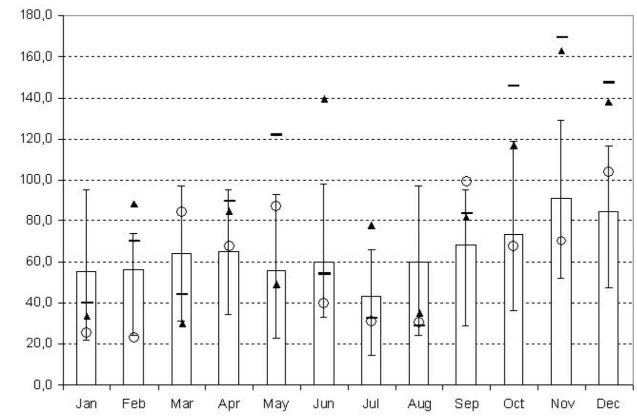


Fig. 3 - Long term average rainfall data compared to 1998 ("minus" symbol), 1999 (black triangle) and 2000 (white circle) data

Fig. 3 - *Dati medi di precipitazione a confronto con i dati rilevati nel 1998 (trattino), 1999 (triangolo nero) and 2000 (cerchio bianco)*

(Figure 5). This representation identified the combinations of the two parameters corresponding to high runoff values and permitted a calibration using this kind of map. The calibrated values for FMIN (between 0.25 and 3.25 mm h^{-1}) are 5% of the values obtained, for each element, with the pedotransfer function developed by Wösten *et al*. (1998) based on the Hypress database for European soils. Although this percentage may appear low, the cali-

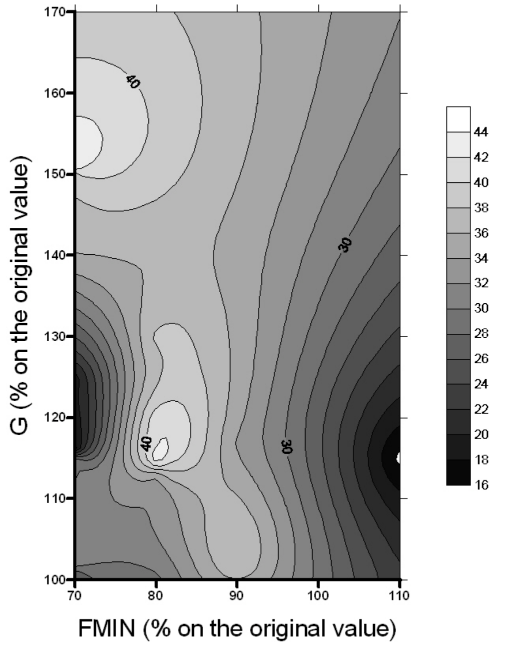


Fig. 5 - Sensitivity analysis (carried out on data from the storm occurred in 11 November 1998). Effects of the co-variation of the parameters FMIN and G (plotted on the two axis) on runoff (mm; represented with contour lines)

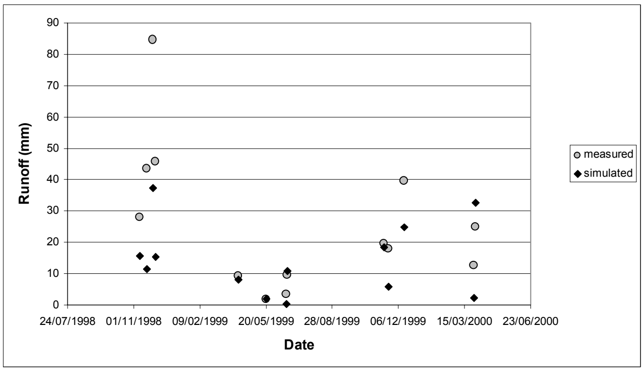
Fig. 5 - *Analisi di sensitività (condotta sui dati rilevati nel corso dell'evento temporalesco del 11 novembre 1998). Effetti della co-variazione dei parametri FMIN e G (disposti sui due assi) sul deflusso (mm; rappresentato da curve di livello)*

brated values for FMIN are always inside the range of values tabled in the EUROSEM manual. Moreover, other authors considered, for FMIN and the same textural classification of the soil, ranges of values that include the ones calibrated in this study (e.g. Tiscareno-Lopez *et al*., 1993; Veihe and Quinton, 2000; Paz Gonzales *et al*., 2003). This may be explained (i) by the high errors in the pedotransfer function for estimating saturated hydraulic conductivity, that are typically of one order of magnitude and (ii) by the fact that the real value of FMIN reduces, by sealing and changes in microtopography, during a single event (Torri *et al*., 1999), on bare soil due to raindrop impact that deteriorates the surface structure and after tillage due to sub-soil layers compaction. At the end of the calibration, the values of G range between 188 and 445 mm. These values are in agreement with the ones reported by Veihe and Quinton (2000).

Calibration of the parameters involved with erosion

The calibrated values of EROD (between 1.9 and 3g J^{-1}) are close to the highest tabled in the EUROSEM user's manual for the same texture classes and are consistent with the values determined by Poesen (1986).

For the parameter COH a unique value was calibrated (10 kPa, close to the lowest values of the EUROSEM manual) for all the elements. This value is included in the range of values reported by Folly (1997). Figure 6 (data from 1998) and Table 2 show EUROSEM performances



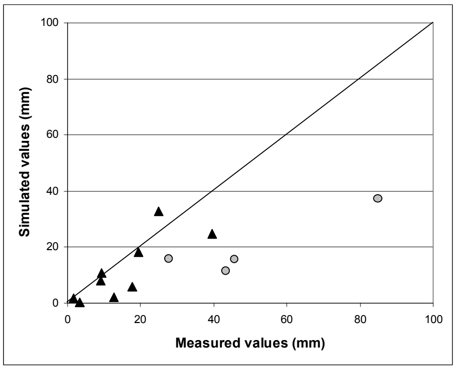


Fig. 6 - Measured and simulated runoff data (cumulated for each event). Evolution in time of the values after calibration (1998) and after validation (1999-2000) (a); measured (X-axis) and simulated (Y-axis) values. Comparison with the y = x ideal function (b)

Fig. 6 - *Valori misurati e simulati di deflusso (totali per evento) a fine calibrazione (1998) e dopo la validazione (1999-2000) (a); confronto con la retta ideale y + x (b; cerchi grigi: calibrazione; triangoli neri: validazione)*

after calibration. It is possible to notice a general model underestimation that we have not corrected with calibration, considering that the model does not include algorithms for the simulation of hypodermic runoff and for water redistribution in soil between two close events. This is also the reason for the unsatisfactory indices of agreement. Because of this consideration, some authors (Folly *et al*., 1999) have already underlined the partial inadequacy of EUROSEM in simulating runoff during long events characterized by more than one peak of rainfall intensity.
Figure 7 (data from 1998) and Table 2 shows the results of erosion simulations. We can observe a generally low agreement between estimated and measured values. Often, over and underestimations compensated each other, producing better fitting indices compared to the ones computed for runoff (EF is positive, parameters of the linear regression equation between observed and predicted values are quite satisfactory, observed and estimated means are close).

Validation

Validation of the parameters involved with the simulation of runoff and erosion is shown in Figures 6 and 7 (data from 1999 and 2000) and in Table 2. Above all for data collected during 1999, the model accurately reproduced both the phenomena. Observed runoff data from 1999 are always reliably reproduced, like the corresponding erosion values (RRMSE = 51.7%, EF, CD and Slope very close to 1, high R^2 and very similar observed and estimated means). For 2000, model results are satisfactory. Considering the complexity (i) of the simulated processes and (ii) of the studied basin, these results are considered encouraging.

Tab. 2 - Indices of agreement between observed and simulated runoff and erosion data

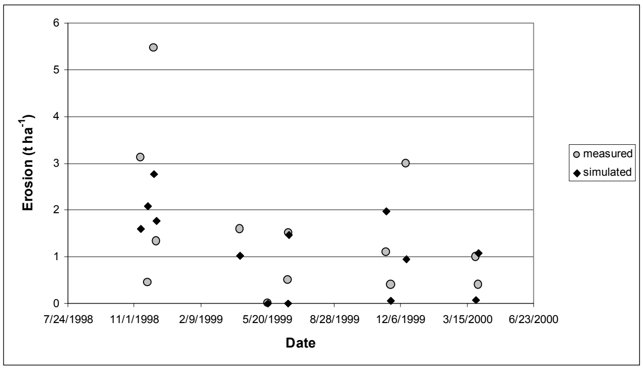
Tab. 2 - *Indici per la valutazione dell'accordo tra dati osservati e simulati di deflusso ed erosione*

	index	RRMSE (%)	EF	CNR	CD	SLOPE	Intercept*	R^2	Signif.	Obs. Mean*	Esti Mea
	Minimum	0.00	-inf.	-inf.	0.00	-inf.	-inf.	-inf.			
	Maximum	+inf.	1.00	+inf.	+inf.	+inf.	+inf.	+inf.			
	Optimal	0.00	1.00	0.00	1.00	1.00	0.00	1.00			
C§	Erosion 1998	83.19	0.48	0.21	0.30	1.44	-0.24	0.56	0.09	1.73	1.3[illegible]
	Runoff 1998	65.44	-1.48	0.61	2.36	1.87	13.32	0.82	0.09	50.50	19.9
V§§	Erosion 1999	51.65	0.80	0.30	0.82	1.08	0.15	0.87	0.01	0.60	0.4[illegible]
	Runoff 1999	79.67	-0.11	0.17	0.92	0.47	0.71	0.19	0.28	1.15	0.9[illegible]
	Erosion 2000					not available					
	Runoff 2000					not available					
T§§§	Erosion 1998/2000	79.92	0.30	0.25	0.42	1.02	0.36	0.37	0.03	1.53	1.1[illegible]
	Runoff 1998/2000	74.42	0.22	0.46	0.55	1.50	4.84	0.58	0.00	26.12	14.1

§:Calibration; §§:Validation ; §§§: Total ; *: for runoff data:mm; for erosion data: t

Comparison with USLE results

Figure 8 shows the annual values of erosion measured, simulated by EUROSEM and estimated with the USLE approach. The USLE estimations are always remarkably high compared with observed data, while the values simulated by EUROSEM are very close to the observed ones for 1998 (observed = 10.38 t ha^{-1} $year^{-1}$; simulated = 8.22 t ha^{-1} $year^{-1}$) and 1999 (observed = 9.22 t ha^{-1} $year^{-1}$; simulated = 7.61 t ha^{-1} $year^{-1}$) and slightly overestimated for 2000 (observed = 1.4 t ha^{-1} $year^{-1}$; simulated = 3.57 t ha^{-1} $year^{-1}$).
These results confirm the inadequacy of the USLE for the Italian Mediterranean environment, already noted by Zanchi (1988). The empirical base of the USLE in the description of the processes and their coefficients generates errors outside the USA, where the coefficients were calibrated.



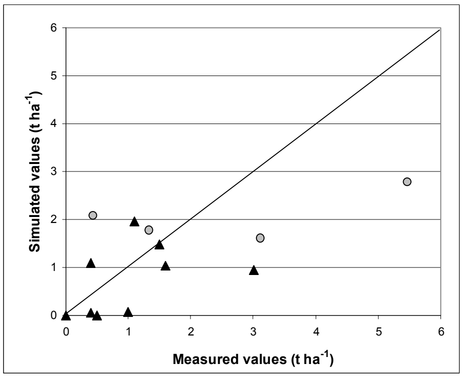


Fig. 7 - Measured and simulated erosion data (cumulated for each event). Evolution in time of the values after calibration (1998) and after validation (1999-2000) (a); measured (X-axis) and simulated (Y-axis) values. Comparison with the y = x ideal function (b)

Fig. *7 - Valori misurati e simulati di erosione (totali per evento) a fine calibrazione (1998) e dopo la validazione (1999-2000) (a); confronto con la retta ideale y = x (b; cerchi grigi: calibrazione; triangoli neri: validazione))*

Conclusions

Although simulated runoff values are not always satisfactory for single events, the model has shown itself to be adequate for simulating hydrological phenomena for a complex system like the one examined in this study. Today, with soil maps, the use of GPS and GIS and greater availability of meteorological data in electronic format, along with improved measuring techniques and pedotransfer functions, data availability is more and more infrequently a major limitation to the applicability of a physical model.

The presence of hypodermic runoff, in case of long events with periods of low rainfall intensity, should explain the observed model underestimation. Other authors have already underscored this discrepancy in the simulation of processes related to water loss from the system (Folly *et al*., 1999; Veihe *et al*., 2001).

Because hydrological processes causing erosion are typically occasional and not continuous, empirical approaches (e.g. USLE) based on just a few years are not sufficient for long-term quantification of erosion and to select agronomical options for its mitigation. EUROSEM, on the contrary, has proven accurate in reproducing annual runoff and erosion dynamics in the environmental conditions of Central Italy. On the basis of the available data, EUROSEM results were well differentiated between different soil cover types (crops [validation] or bare soil [calibration], and within the same crop, vegetative stages) and were able to take into account specific meteorological phenomena within each year, while also proving itself a useful tool for testing the effects of different climatic and management scenarios

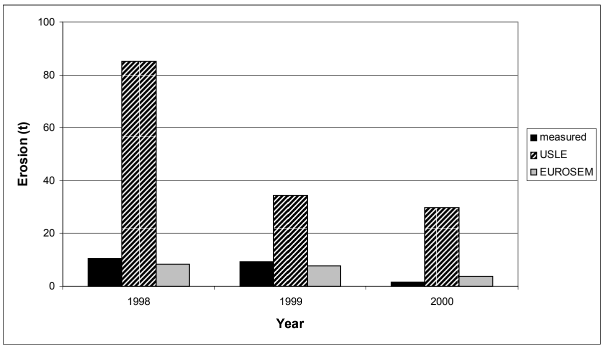


Fig. 8 - Yearly observed erosion values compared with the ones simulated by EUROSEM and estimated with the USLE approach

Fig. 8 *- Figura 8. Valori annuali di erosione osservati, simulati da EUROSEM e stimati con USLE*

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