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Actions Against Soil Erosion at the Single Field and the Catchment Scale Guided by Computer Simulation

J. Schmidt, W. Schmidt, M.v. Werner and A. Michael*

ABSTRACT

This contribution reports on computer simulations assessing different agricultural measures of soil erosion control: conservation tillage; optimization of the road and drainage system; grassed waterways; and buffer strips.

The simulations were performed for different sites in Saxony (Germany), based on the EROSION 2D/3D model, which is a process-based soil erosion model for simulating soil erosion and soil deposition by water on slopes (2D) and small catchments (3D). The theoretical concept of the model is established on the momentum flux approach developed by Schmidt (1991). Based on estimates of the actual soil loss the model results allow to assess the effectiveness of specific erosion control measures under different soil, crop, and weather conditions.

INTRODUCTION

The design and implementation of soil erosion control measures requires detailed spatial information of the actual or expected risk of erosion and associated on-site and off-site effects. Computer-based soil erosion models are increasingly used, in order to gain such information and to simulate the effects of different soil erosion control measures. The first mathematical approach to describe soil erosion by water, the Universal Soil Loss Equation (USLE) by Wischmeier & Smith (1965), was derived by correlating the amount of soil loss gained from experimental plots with various topographic, climate, soil, and land use parameters. More recently developed soil erosion models as for example WEPP (Lane & Nearing 1989), EUROSEM/KINEROS (Morgan 1992; Woolhiser et al. 1990), EROSION 2D/3D (Schmidt 1991, 1996) mainly use physically based approaches, which allow adequate representation and quantitative estimation of erosion (soil detachment and transport) and deposition.

Based on applications of the EROSION 2D/3D model this paper presents some examples for the use of computer simulation in soil conservation planning and assessment. The computations refer to different sites in Saxony, which is located in the eastern part of Germany. The soils of this part of the country developed predominantly from loess-sediments. For this reason they are very productive, but also very sensitive to erosion.

The following measures of soil erosion control were simulated:

- Conservation tillage
- Optimization of the road and drainage system
- Grassed waterways
- Buffer strips.

EROSION 2D/3D

The EROSION 2D/3D model was developed with the intention to create an easy-to-use tool for soil erosion prediction. The first implementation of the model was a PC-version of EROSION 2D, which describes erosion and deposition for a 1m wide slope profile. After intensive validation and numerous practical tests an improved catchment version (EROSION 3D) was developed (v. Werner 1995). To promote the applicability of the model a detailed handbook was published including a compilation of experimentally obtained parameter sets for different soils and crops (Schmidt et al. 1997).

The EROSION 2D/3D model is predominantly based on physical principles: Erosion is limited either by the amount of sediment that can be detached from the soil surface or by the transport capacity of the flow.

The basic idea of the model is the assumption that the erosive impacts of overland flow and rain droplets are proportional to the momentum flux exerted by the flow and falling droplets respectively. In analogy to that erosional resistance of the soil is expressed in a form of a critical momentum flux. The model is able to describe both soil erosion and soil deposition on slopes (2D) and small catchments (3D) up to about one hundred square kilometers in size.

The impacts of different types of land use and management systems on soil erosion are represented in the model by the following dynamic parameters of soil erosion control:

- Bulk density
- Organic matter content
- Resistance to erosion
- (Hydraulic) roughness of the soil surface
- Soil cover

In addition soil texture, topography and precipitation parameters enter the model calculations but are not affected by tillage operations.

The spatial variability of the input parameter values is accounted in the 2D and 3D model by a grid-cell data representation of the slope or the watershed respectively. The following output parameters are calculated for each grid cell:

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*J. Schmidt, W. Schmidt, M.v. Werner , and A. Michael, Technical University Freiberg, Soil and Water Conservation Unit, Agricolastrasse 22, D-09599 Freiberg, Germany. *Corresponding author jschmidt@orion.hrz.tu-freiberg.de

a) Related to area:

- Erosion and deposition for the chosen grid cell (mass/unit area)
- Erosion, deposition and net erosion for the watershed draining into the chosen grid cell (mass/unit area)

b) Related to cross-section of flow:

- Runoff (volume/unit width)
- Sediment delivery (mass/unit width)
- Sediment concentration (mass/unit flow volume)
- Particle-size distribution of the suspended sediment (percentages by mass of clay, silt and sand).

MODEL APPLICATIONS

Conservation tillage

Conservation tillage aims to reduce or even prevent the mobilization of soil particles by leaving plant residues on the soil surface. The main effect of this measure is the protection of the soil surface from splash impact. The residue cover also reduces the eroding impact of surface runoff due to the increased roughness of the soil surface.

Using the EROSION 2D model the effects of conservation tillage was demonstrated with respect to a single slope profile and different temporal scales, i.e. a single rainstorm, a single year and a period of 12 years. The results of the various simulation runs are summarized in Table 1. They show, that soil loss can be reduced dramatically, if conservation tillage practices are used instead of conventionally techniques.

Referring to the single rainstorm (10-year return period) simulation, Figure 1 displays the computation results in more detail. The upper graph a) represents the slope profile. The two figures below show the calculated soil loss and deposition: graph b) refers to conventional tillage and graph c) to conservation tillage.

For the long-term simulations (s. Table 1) a "reference-year" was used which represents the average rainfall distribution during one year. In order to assess the effects of a crop rotation (sugar beets, winter-barley, summer-wheat) on soil loss several reference years including a 5-year and a 10-year rainstorm were combined to cover a period of 12 years in total.

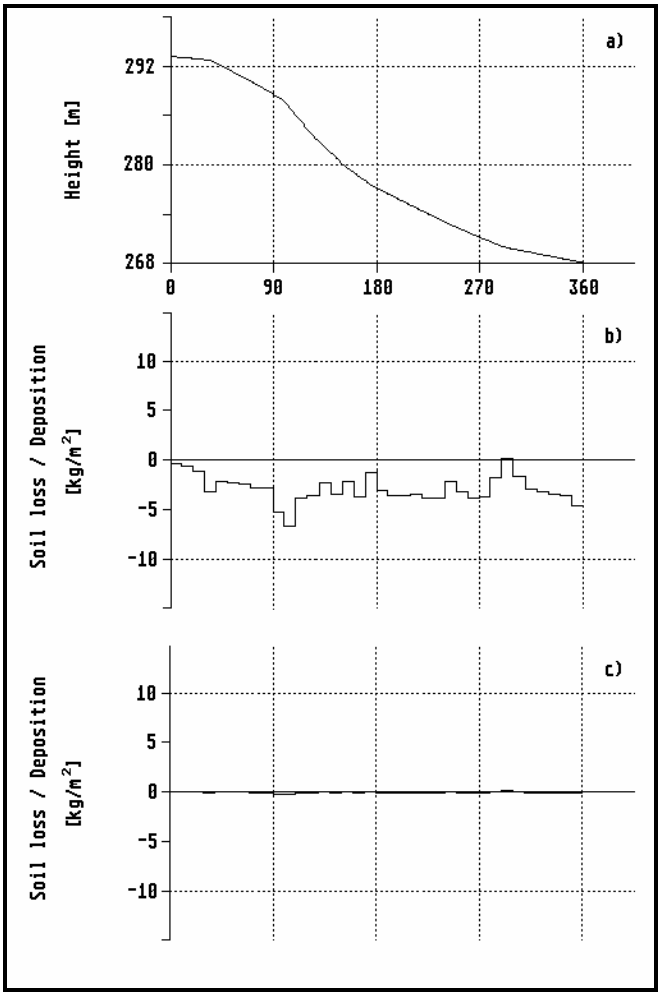

Figure 1. Spatial distribution of soil erosion and deposition on a loessy hillslope in Saxony (Germany), predicted with the EROSION 2D model. The simulation is performed for a rainstorm with a return period of 10 years, i.e. of a total rainfall depth of 22.2 mm and total duration of 40 min. a) Hillslope profile. b) Distribution of erosion and deposition for conventionally-tilled sugar beets (3-leaves stage). c) Distribution of soil erosion and deposition for the same but conservation-tilled slope with mulch-seeded sugar beets.

Table 1. EROSION 2D predictions of soil loss from a conventionally and conservation-tilled clayey silt in the Loessy Hill Region of Saxony (Germany). The simulations are performed for a rainfall event with a return period of 10 years, a reference year and a period of 12 years.

	Soil loss	
Temporal scale	Conventional tillage [t/ha]	Conservation tillage with mulch seeding [t/ha]
Single rainstorm (10-year return period)	26.0	1.5
Reference year (22 erosive rainfall events)	23.7	0
12-year period (including a 5-year and a 10-year rainfall event)	196.0	2.6

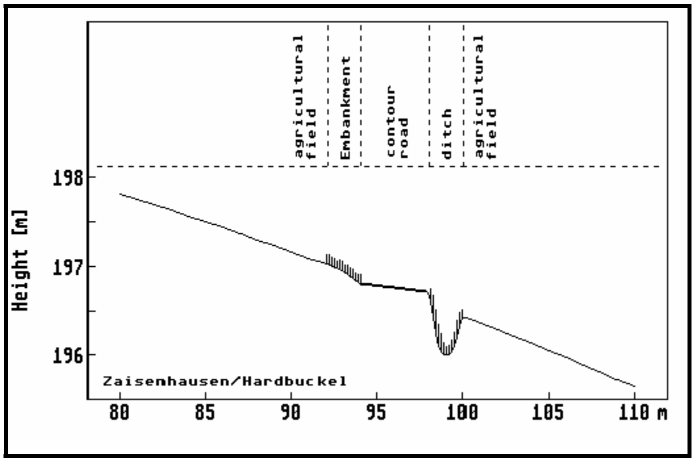

Figure 2. Principal layout of a contour road with diversion ditch (Schmidt, J., 1996, p. 114).

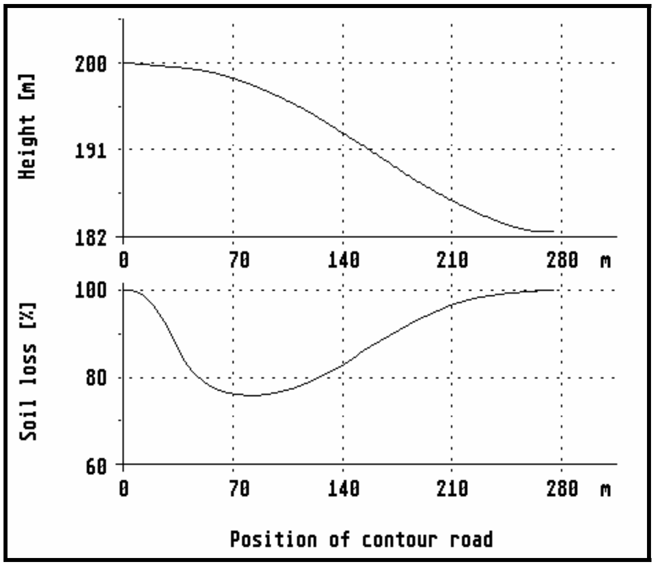

Figure 3. Influence of the position of a combined contour road and ditch on soil loss. The plotted values are normalized to the soil loss (= 100 %) from the same but undivided slope (Schmidt, J. 1996, p. 116).

Table 2. Reduction in soil loss achieved by applying different conservation measures to a 4.1 km^2 agricultural watershed. The predictions are based on a rainstorm with a return period of 10 years.

Management practice / field condition	Soil loss [t/ha]
Conventional tillage / no soil cover	124.3
Conventional tillage / no soil cover + grassed waterways	100.2
Conservation tillage / 50 % mulch cover + grassed waterways	2.3

Optimization of the Road and Drainage Network

The division of large fields into smaller units by contour roads and diversion ditches is a commonly used measure of soil erosion control. The EROSION 2D model was applied to identify that slope position of a combined contour road and diversion ditch (Figure 2) at which the soil loss from the entire field is reduced most. In order to find that position the combined contour road and diversion ditch were shifted virtually from the upper towards the lower end of the slope. The predicted soil loss from the divided slope was normalized to the soil loss from the undivided slope (= 100 %) and plotted over the entire length of the slope (Figure 3). The following conclusions can be drawn from the resulting curve:

- The relative soil loss is 100 % if the contour road and the diversion ditch are located exactly at the upper or lower end of the slope. Every other position on the slope profile leads to a reduction in soil loss.
- The maximum reduction is achieved if the contour road and the diversion ditch are located in the upper half of the slope. For the investigated profile, the optimal distance of the road from the upper end of the slope is approximately 80 m. At that point, soil loss is reduced by about 22%.

Grassed Waterways

In many cases, the spatial layout of agricultural fields ignores smaller natural slope depressions and waterways, resulting in the concentration of surface runoff and severe erosion at the bottom of the depressions. The erosive impact of concentrated overland flow can be reduced by reestablishing permanent vegetation in these waterways.

The effectiveness of such a measure was demonstrated by applying the EROSION 3D model to a small watershed in the Loess Hills of Saxony, which are predominantly used as cropland.

The soil loss was simulated for a single rainstorm with a return period of 10 years using following conditions:

- seedbed preparation after conventional tillage, no plant cover
- high initial soil moisture (field capacity) from previous rainfall.

Figure 4 shows the predicted spatial distribution of erosion and deposition for the described scenario. Erosion is indicated by yellow to red colors, and green to blue colors are assigned to areas of deposition. The depressions within the fields can be clearly identified as red strips. As indicated by the green and blue colors, the major part of the eroded soil is intercepted by the lower valley and floodplain areas, which are used as rangeland. However, at least a short section of the road parallel to the eastern margin of the field is buried by the deposited soil due to its proximity to the eroded field.

For the simulation of the grassed waterways conservation scenario, the red areas of severe erosion (soil loss > 25 kg/m^2) were "virtually" converted to rangeland. In addition, conservation management practices with mulch seeding (50 % cover) were assumed for the cropland. All other conditions (i.e. precipitation, field size) remained identical. The erosion predicted for this management scenario is plotted in Figure 5. The map shows that a considerable reduction of soil loss is achieved by these measures, as indicated by the prevailing yellow colors (i.e. soil loss < 7 kg/m^2).

The results compiled in Table 2 show that the soil loss is reduced by about 20 % solely by implementing grassed waterways in the bottom areas of the depressions. The soil loss from the agricultural land can be further reduced by about 98 % if all cropland is managed with conservation tillage and mulch seeding.

Buffer Strips

The long-term, continuous delivery of eroded soil sediments leads to the silting-up of still-water reaches and reservoirs and, finally, to the loss of ecological and economic functions. The maintenance and restoration of these functions usually cause high costs. Buffer strips are commonly used in order to retain the sediments before they enter the drainage network.

Figure 6 shows the spatial distribution of erosion and deposition for the catchment area of a drinking water reservoir at the Ore Mountains of Saxony (Germany) as predicted by EROSION 3D for a single rainfall event. When

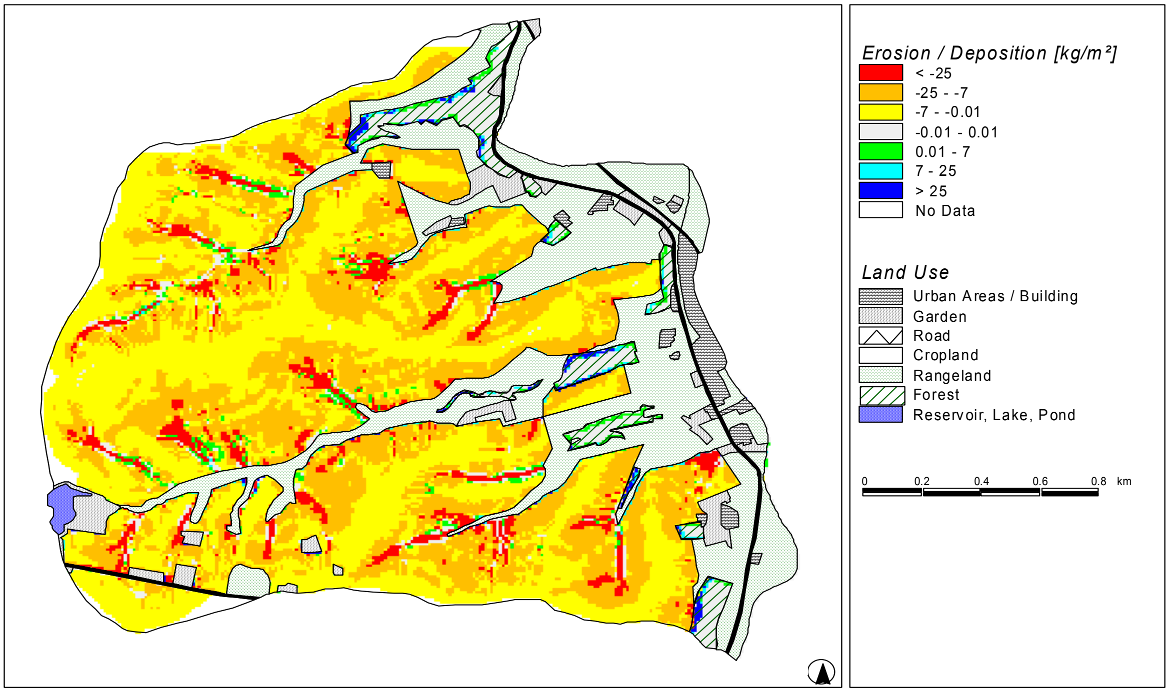

Figure 4. **Erosion map calculated by EROSION 3D for a 4.1 km^2 agricultural watershed in the Loessy Hill Region of Saxony. Conventional tillage practices, seedbed conditions, initial soil moisture at field capacity, and a rainstorm with a return period of 10 years were used as inputs to the simulation (Schmidt, J., Michael, A., v. Werner, M. 1998).**

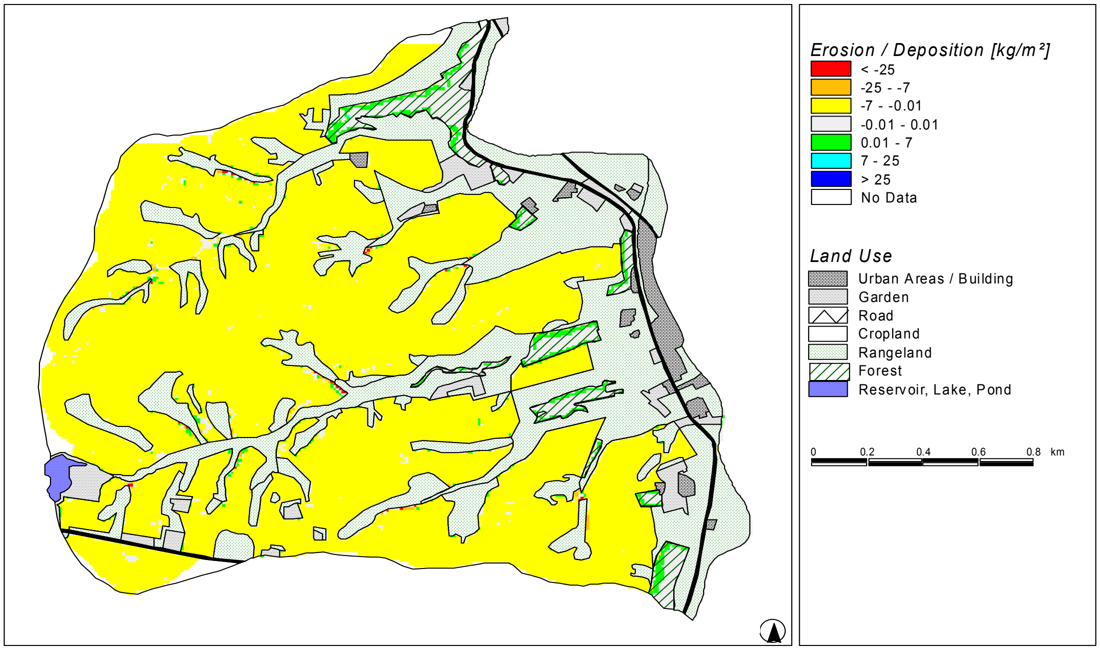

Figure 5. **Erosion map for the same watershed and initial conditions as plotted in Figure 4, but conservation tillage practices with 50% mulch cover and grassed waterways (Schmidt, J., Michael, A., v. Werner, M. 1998).**

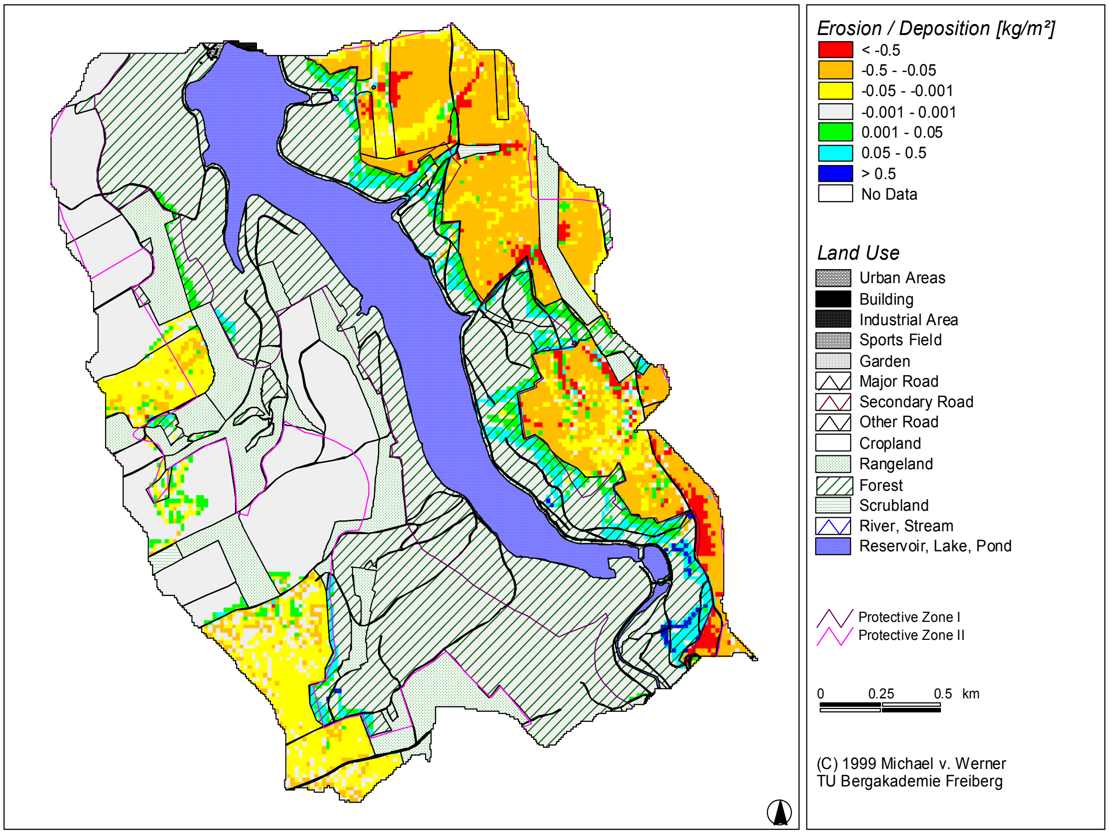

Figure 6. Erosion map for subwatershed 1 of the Klingenberg-Lehnmühle watershed (predicted for the rainfall event on July, 7 of the reference-year rainfall scenario; Schmidt & von Werner, 1998).

Table 3. Mean relative deviation between measured soil losses and EROSION 2D/3D predictions.

Location	**Size**	**Time basis**	**Mean relative deviation**
based on plot measurements:			[%]
Mistelbach (Klik et al. 1998)	L: 15m, W: 3m	Year	78
Frankenforst(Botschek 1999)	L: 10m	Single event(rainfall simulation)	53
Methau(Schröder 2000)	L: 22m, W: 2m	Single event(rainfall simulation)	92
Möhlin(Hebel et al. 2000)	L: 10m, W: 3m	Year	35
Länenbachtal(Hebel et al. 2000)	L : 20m, W: 3m	Year	78
based on catchment measurements:			
Catsop (NL) (Schmidt et al. 1999)	42 ha	Year 1993:1987:	76(+)2816
Hölzelbach(Schmidt u. v. Werner 2000)	73ha	Year (mean)	25
Hohenfels military training area (Deinlein & Böhm 2000)	41ha	Single event	21

the reservoir was established a forest strip was planted all around the reservoir in order to retain eroded sediments from the agricultural areas nearby. Actually, the forest strip intercepts most of the soil material as indicated by the green and blue colors in that area. However, at some locations the sediment passes through the forest and enters the reservoir.

By identifying these locations, the model can help to improve sediment control in that area.

VALIDATION OF MODEL RESULTS

The EROSION 2D/3D model was validated by extensive sensitivity analyses, plausibility tests and comparisons with measured data (Schmidt, 1996). Tab. 3 summarizes some error estimations from recent erosion studies at the plot and the catchment scale. As the results show, the performance of the model is acceptable considering the possible errors in assessing the model inputs. In addition, errors in the measured data or deficits in the model design might be important. This is true especially at the catchment scale because in the present model version channel processes are not represented by specific algorithms. All sediment, which enters the channel, is transferred all at once to the catchment outlet. With respect to a certain runoff event, this assumption might not be true. To some extent, the exceptional errors that we have got for the Catsop events in 1987 might be caused by channel effects (especially channel deposition). In the long run, however, deposition and erosion within the channel will compensate so that their effect on sediment yield can be neglected. Accordingly, long-term simulations of sediment yield should give better results than those for single event or a single year.

CONCLUSIONS

As demonstrated, model simulations provide specific information on the spatial and temporal variation of soil loss and deposition, which could hardly be attained empirically. For that reason process-based soil erosion models such as EROSION 2D and 3D can be a helpful tool in order to guide soil erosion control measures. Model applications may range from:

- the estimation of erosion risks and the identification of problem areas to
- the information and training of farmers particularly with respect to conservation tillage practices or to
- the planning and optimization of soil erosion control measures.

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