Sediment transport in a small agricultural watershed—evaluation of WEPP simulations with measured data

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Abstract During the 2002 growing season spatially and temporally distributed data on surface runoff, soil erosion, soil water content and crop development were collected from a 16-ha watershed in lower Austria, for which there was no information on water and sediment output. The watershed version of the Water Erosion Prediction Project (WEPP) model was applied without calibration to calculate the spatial distribution of erosion processes within the watershed. The field measured data were used to validate the simulation results. A good agreement between observed and simulated values was obtained for surface runoff, soil water storage and crop yields, whereas soil erosion was underestimated. Overall, WEPP is a useful and appropriate tool for estimating sediment transport in small agricultural used watersheds. However, calibration of the model input parameters is needed to improve sediment loss predictions.

Key words Austria; simulation models; soil erosion; surface runoff; WEPP

INTRODUCTION

Soil erosion and sediment loss are becoming increasingly greater concerns in the world, due to on-site impacts reducing soil quality and the off-site impacts of impaired water quality. New legislation and policies are likely become reliant upon computer models to assess the current status of a watershed and evaluate the effects of implementing a variety of alternative management strategies.

The Water Erosion Prediction Project (WEPP; Flanagan & Nearing, 1995) model is a process-based continuous simulation erosion model. The watershed version can be used to estimate runoff and erosion processes within small watersheds as well as watershed runoff and sediment yield. Several studies have been conducted to compare hillslope predictions with measured plot runoff (Zhang *et al*., 1996; Klik & Zartl, 2001). Few attempts (Savabi *et al*., 1996; Nearing & Nicks, 1997) have been made to evaluate the accuracy of WEPP watershed model calculations by comparing predicted results with measured data.

The objective of this study was to apply the WEPP watershed model to a small agricultural watershed in Austria and to evaluate the model performance based on: (a) measured runoff and soil loss data from 24 erosion plots installed in the watershed, and (b) crop yield, crop development and spatially distributed soil water content data.

MATERIALS AND METHODS

Watershed description

The study was carried out in a 16-ha agricultural watershed in Mistelbach, Austria, which is located in the so-called "Wine Quarter" (48°34′N, 16°34′E). The watershed has a rolling topography, with slope gradients of 2–6% on the ridges and valleys and 12–18% on the side slopes. The total relief of the study watershed is about 30 m and the maximum overland flow path about 480 m. This region is one of the warmest, but also driest, parts of Austria. Average annual precipitation is 645 mm, mean annual temperature is 9.6°C. The soils are classified as Typic Argiudoll with mixed mineralogy and a mesic temperature regime. Soil textures of the top soil (0–30 cm) are silt loam and silt clay loam respectively, with sand contents between 6 and 22% and clay contents ranging from 19 to 32%. In 2001 and 2002 winter barley, sunflower, canola, corn and winter wheat were planted as main crops.

Field measurements

To investigate soil erosion and deposition processes, 24 erosion plots with areas between 1 and 45 m^2 were installed in different fields during the 2002 growing season, in order to obtain spatially distributed runoff and soil loss data for each erosive event. Precipitation and air temperature were collected at 5-min intervals.

In November 2001, and April and July 2002 soil water content measurements were performed on a 25 × 25 m grid for the 0–60 cm soil depth. During the 2002 growing season the development of plant cover and plant height was observed at preselected time intervals for the five planted crops and crop yield data were collected.

Simulation model

For simulations, the WEPP watershed version was used (Flanagan & Nearing, 1995). WEPP required climate, slope, management and soil input files, which were assembled using the gathered information. For the climate input file, breakpoint data (precipitation) and daily averages (temperature) were used. Crop characteristics required for hydrological calculations were taken from the WEPP crop database and supplemented with site-specific data. Tillage implements were selected from the WEPP equipment database and if necessary modified for Austrian tillage practices. Physical and chemical soil input parameters were derived from information provided by the Austrian Soil Survey (Österreichische Bodenkartierung, 1995) and from measurements undertaken for the study. Soil erodibilities were calculated according to the recommendations of WEPP.

Based on the field layout and the topography, the watershed area of 15.94 ha (Tables 1 and 2) was divided into 17 subwatersheds with areas ranging from 0.12 to 1.63 ha (Fig. 1, Table 1). These were connected through 13 channels, with a total area of 0.11 ha (Fig. 1, Table 2). For each subwatershed, a representative hillslope was selected and then, if necessary, divided into different overland flow elements (OFE) corresponding to the existing soil–vegetation conditions (Table 1).

Fig. 1 Watershed showing the layout of the hillslope and channel system.

Table 1 Characteristics of subwatersheds and representative hillslopes.

Hillslope no.	Length (m)	Width (m)	Area (m^2)	Crops	No. of OFE	Av. Slope (%)
1	196.2	83.2	16 313	Canola	2	3.5
2	94.2	125.6	11 831	Sunflower	1	5.9
3	247.2	59.3	14 648	Winter barley	2	5.7
4	221.7	27.8	6 164	Winter barley	2	4.5
5	170.5	75.9	12 933	Sunflower	4	7.0
6	53.8	125.3	6 740	Sunflower	2	9.7
7	120.5	95.0	11 440	Canola – sunflower	2	9.2
8	52.2	22.8	1 190	Sunflower	2	8.0
9	130.2	31.0	4 028	Sunflower	2	7.1
10	134.7	37.0	4 977	Winter barley – sunflower	4	8.8
11	132.9	33.2	4 408	Winter barley – corn	4	8.7
12	174.3	32.4	5 646	Canola – corn	4	9.0
13	136.1	71.6	9 739	Winter wheat	2	14.2
14	97.8	144.1	14 088	Winter wheat	2	12.4
15	69.5	106.2	7 387	Winter wheat	2	18.1
16	128.6	113.6	14 608	Canola	4	11.8
17	108.8	111.7	12 146	Canola	2	12.0
Total			158 358			

Table 2 Characteristics of channels.

Channel no.	Length (m)	Width (m)	Area (m^2)	Contributing channel	Contributing HS	Av. slope (%)
1	27.7	2	55.4	2	16, 17	8.8
2	57.3	2	114.6	3	14, 15	10.5
3	81.5	2	163.0	4	13	8.3
4	93.9	2	187.8	5, 9, 10	11, 12	7.3
5	29.0	1	29.0	6	9	5.2
6	29.0	1	29.0	7	5, 8	4.2
7	32.5	1	32.5	8	–	8.6
8	71.0	1	71.0	–	2, 6	4.4
9	74.1	1	74.1	12	10	8.0
10	104.9	1	104.9	11	7	3.9
11	113.4	1	113.4	–	1	4.0
12	86.3	1	86.3	13	3	7.3
13	64.3	1	64.3	–	4	5.5
Total			1125.0			

RESULTS

Runoff and soil loss on the plot scale

Event based runoff and soil loss measurements from the 1 × 1 m and 2 × 3 m plots were used for verification of the WEPP model. Erosion plots were installed in fields cropped with sunflower, canola and corn. During the observation period, seven erosive rainfall events occurred from the beginning of May until the middle of August 2002. The rainfall amounts associated with these storm events ranged from 19.6 to 70.7 mm, with maximum 30-min intensities (I_{30}) between 5.36 and 34.54 mm h^{-1}. All of them led to runoff and soil loss from sunflower and corn planted plots. Data are available from only three events for the canola plots, because these were removed at the beginning of July 2002 after the harvest. As the area of the erosion plots covers only 1–6 m^2, the main erosion process was interrill erosion. Therefore, the field measured soil losses were compared with the WEPP calculated interrill erosion rates from the corresponding hillslopes and OFEs, where the plots were located. For two storm events in June and August with rainfall amounts of 49.9 and 70.7 mm, respectively, the simulations overpredicted runoff from corn (in June) and canola plots (in August, Fig. 2). The cause of this discrepancy cannot be readily explained. Based on 32 data sets, these comparisons showed that without any calibration the WEPP model calculated acceptable runoff values, but underpredicted soil loss (Fig. 2). Overall average runoff amounts were 4.92 mm (±6.62 mm) from observations and 7.58 mm (±8.33 mm) from simulations (Table 3). Runoff values from plots planted with sunflower showed a good agreement between measurement and prediction (8.39 mm *vs* 9.05 mm) whereas values from canola plots disagreed (0.81 mm *vs* 5.85 mm). For event based soil loss values, average erosion rates of 1.28 t ha^{-1} (±2.22) and 0.39 t ha^{-1} (±0.72), respectively, were observed and calculated (Table 3). For most crops (except canola) soil erosion was underestimated. The same trend with reasonable runoff calculation and erosion

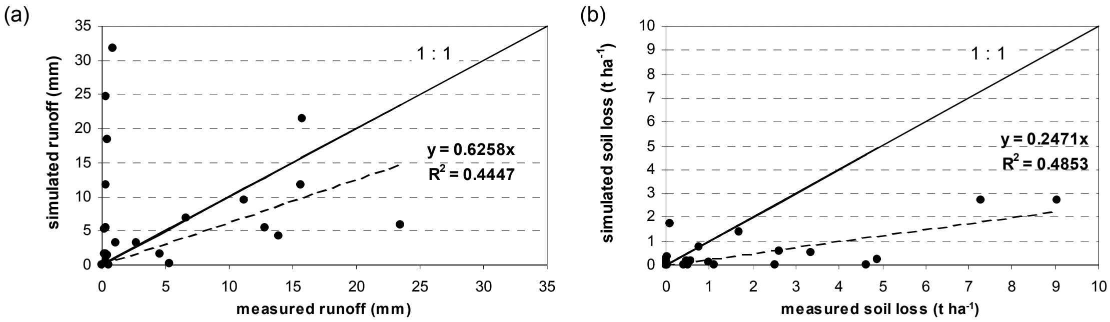

Fig. 2 Measured *vs* (a) simulated runoff and (b) soil loss.

Table 3 Average measured and simulated runoff and soil loss from sunflower, canola and corn planted erosion plots.

Crop	No. of observations	Runoff (mm): Measured	Simulated	Soil loss (t ha^{-1}): Measured	Simulated
Sunflower	11	8.39	9.05	1.55	0.21
Canola	13	0.81	5.85	0.02	0.22
Corn	8	n.a.	n.a.	2.59	0.92
Sum/average	32	4.92	7.58	1.28	0.39

underestimation was found when comparing 6-year runoff and erosion data from field erosion plots (Klik & Zartl, 2001). On the other hand studies by Liu *et al.* (1997) and Cochrane & Flanagan (1999) showed that WEPP provides reasonable estimates of runoff and sediment yield when applied to small agricultural watersheds.

Plant development

Canopy height and canopy cover investigations were performed in the field for corn, canola, sunflower, winter wheat and winter barley. The evaluation of the results showed that WEPP was able to simulate the temporal course of plant height and plant cover, even if the agreement between measurement and simulation was slightly better for plant cover than for plant height.

For the growing season 2002, crop yields were available for canola, winter wheat, sunflower and corn. When comparing these values with simulation results a satisfactory agreement was found (Fig. 3).

Soil water content

Grid-based soil water content measurements (159 points) for a soil depth of 0–60 cm were evaluated for each hillslope. For the same dates, WEPP simulated soil water results were related to a soil depth of 60 cm and then compared with the field measured values. The comparison showed a high level of agreement between both data sets, especially in autumn and spring (Fig. 4, Table 4). In spring and autumn, measurements and simulations differed on average by only 1–4%. In summer WEPP simulated a 26% higher mean soil water storage. Standard deviations of simulated values for all dates

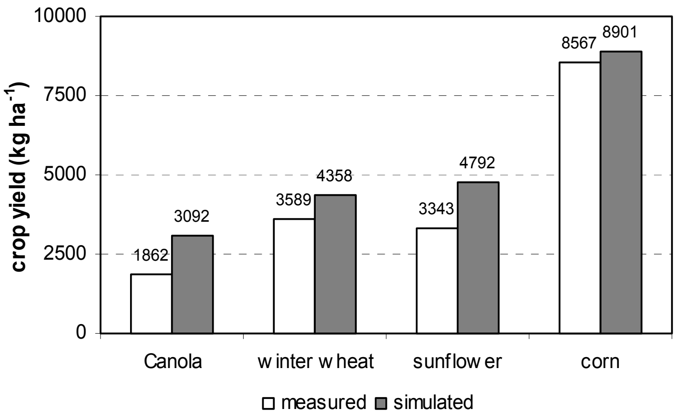

Fig. 3 Measured *vs* simulated crop yields.

Table 4 Measured and simulated soil water storage for a depth of 0–60 cm.

Date	Average		SD	
	Measured	Simulated	Measured	Simulated
11 November 2001	147.4	153.1	11.2	14.9
8 April 2002	143.7	145.5	10.7	22.8
2 July 2002	87.2	109.9	12.3	32.8

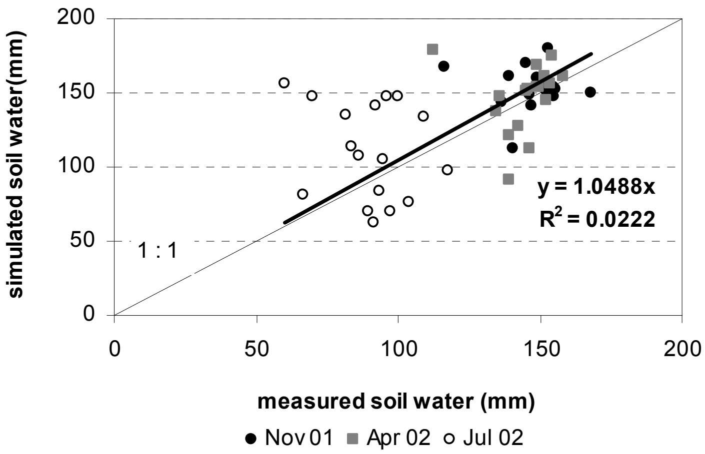

Fig. 4 Comparison of measured and calculated soil water storage (0–60 cm soil depth).

were in the same range as for observed values, indicating that WEPP is able to simulate similar variability.

Runoff and soil loss on the watershed scale

The runoff and soil loss simulation was performed for the whole watershed for the years 2001 and 2002. The results relating to average annual runoff, soil loss,

Table 5 Simulation results for subwatersheds.

Hillslope no.	Runoff (mm year^{-1})	Soil Loss (t ha^{-1} year^{-1})	Deposition (t ha^{-1} year^{-1})	Sediment yield (t ha^{-1} year^{-1})
1	18.6	0.11	0	0.11
2	4.3	2.56	0	2.56
3	13.8	0.07	0	0.07
4	0	0	0	0
5	4.9	6.87	0	6.87
6	26.0	15.08	0	15.08
7	31.4	10.13	0	10.13
8	15.1	7.65	0	7.65
9	8.7	8.81	0.19	8.62
10	6.7	16.45	0.66	5.79
11	13.0	32.75	11.36	21.39
12	4.7	8.89	0.90	7.99
13	7.7	2.11	0	2.11
14	7.6	1.52	0.01	1.51
15	2.8	0.09	0	0.09
16	1.8	0.35	0.09	0.26
17	15.3	1.99	0	1.99
Total	9.8	4.31	0.38	3.93

deposition and sediment yield for each subwatershed are compiled in Table 5. Substantial spatial variability in soil loss was observed in the watershed. An average annual soil loss of 68.27 t and an average deposition of 6.06 t were calculated for the 15.84 ha of the subwatersheds. These values correspond to a soil loss of 4.31 t ha^{-1} year^{-1} and a deposition of 0.38 t ha^{-1} year^{-1}. Only one subwatershed (#4), located at the northwest border of the watershed, showed no erosion. In all other subwatersheds soil loss, and sometimes deposition also, occurred. Planting of small grains (#3, 4, 13, 14, 15) resulted in lowest erosion values (0–2.11 t ha^{-1} year^{-1}), while corn (#11, 12) and sunflower (# 2, 5, 6, 8, 9) led to the highest soil loss values (7.65–32.75 t ha^{-1} year^{-1}). Planting of canola (#1, 16, 17) also reduced soil loss (0.11–1.99 t ha^{-1} year^{-1}) due to the dense plant cover during the spring, when most of the erosive storms occur. In six subwatersheds a redistribution of soil by both erosion and deposition was predicted. The deposition ranged from 0.01 to 11.36 t ha^{-1} year^{-1}. The sediment yield leaving the hillslopes and entering the channels ranged from 0–11.6 t per field (Fig. 5) or 0–21.39 t ha year^{-1} (Table 5), respectively.

In Table 6 the sediment routing through the channel system is presented. For each channel the sediment input from adjacent hillslopes and channels, erosion and deposition within the channel, and sediment delivery to the adjacent channel, are compiled. In the 13 channels, erosion as well as sedimentation occur. In eight channels erosion was the controlling process, while in four other channels it was deposition (Table 6). Annual erosion of 11.75 t of *vs* sedimentation 16.46 t year^{-1} resulted in an annual net deposition of 4.71 t in the channel system. Considering the whole watershed, a runoff volume of 1552 m^3 and an average sediment yield of 57.5 t were calculated to leave the outlet of the watershed (Channel 1), These values are equivalent to annual values of surface runoff of 9.73 mm and sediment yield of 3.63 t ha year^{-1}.

Fig. 5 Sediment delivery from the hillslopes to the channel system within the watershed.

Table 6 Average annual calculated erosion and deposition in the watershed.

Channel no.	Input from:		Process in the channel:		Sediment yield
	Hillslopes ($t\ year^{-1}$)	Channels ($t\ year^{-1}$)	Erosion ($t\ year^{-1}$)	Deposition ($t\ year^{-1}$)	($t\ year^{-1}$)
8	13.19	–	0	10.09	3.1
7	0	3.1	9.1	0	12.2
6	9.80	12.2	0	1.40	20.6
5	3.47	20.6	0	2.87	21.2
13	0	–	0	0	0
12	0.10	0	0.10	0	0.2
9	2.88	0.2	0.52	0	3.6
11	0.19	–	0.21	0	0.4
10	11.59	0.4	0.91	0	12.9
4	13.94	37.7	0.66	0	52.3
3	2.05	52.3	0.15	0	54.5
2	2.21	54.5	0	2.10	54.6
1	2.78	54.6	0.10	0	57.5

SUMMARY

The WEPP watershed model produced reasonable results when applied to the small agricultural watershed. An acceptable agreement was found between measured and simulated runoff while soil loss was underestimated. WEPP was able to predict the magnitude and spatial variability of soil water content in the watershed as well as crop development and crop yields. Overall, considering that the model was run without any calibration, the performance of WEPP was quite satisfactory. However, calibration of the model input parameters will improve sediment loss predictions.

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