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EVALUATING THE EFFECT OF WEPP PREDICTIONS OF RUNOFF AND SOIL LOSSES IN THE LOESS PLATEAU REGION OF CHINA

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In this paper, we evaluated the Water Erosion Prediction Project (WEPP) model using 5-yr monitored runoff and sediment data from three different lands cover treatments in the Loess Plateau of China. The results showed that the WEPP model was able to predict 22 out of 37 recorded runoff producing events, and 20 out of 34 recorded sediment producing events. Prediction of annual runoff is more accurate than the prediction of sediment. The correlation coefficients between the annual monitored and simulated runoff ranged from 0.69 to 0.91, and 0.11 to 0.90 for sediment; for the three treatments (bare, corn and grass), the prediction for the grass plot is better than the other two. Soil moisture and storm intensity appeared to have greater effect on both predictability and accuracy of runoff events and sediment yields. For grass plot, Nash-Sutcliffe coefficient was 0.76 in runoff and 0.56 in sediment. WEPP predictions for the grass plot were in agreement with measured values, but no better than using the averaged measured values for the other two treatments (bare and corn plots). Application of the WEPP model should be decided with precautions in the Loess Plateau area.
Keywords: Soil erosion**,** runoff, soil loss, soil structure, land cover, sediment content.

INTRODUCTION

The Loess Plateau in north western of China is one of the most erosion-prone regions in the world (Chen *et al*., 2007; Tang *et al*., 1993). It covers an area of 640,000 km^2 with the climatic conditions range from the semi-arid in the north to the sub-humid in the south (Su *et al*., 2013). The vulnerability of the region to soil erosion ascribes to the loose structure of the local soil, which is further compounded by intensive farming and grazing (Huang *et al*., 2004; Wei *et al*., 2007; Xu *et al*., 2014). The local government has made great efforts to control soil erosion and restore the ecosystem since the 1950s (Wang *et al.*, 2013; Zhou *et al*., 2006). Soil erosion, however, is still out of control in most of the erosion prone areas (Chen *et al*., 2007). Many researchers have been studying the erosion processes in the Loess Plateau area with continuing efforts (Evans *et al*., 1994; Fu *et al*., 2005; Li *et al*., 2011).

Existing studies indicated that soil erosion was affected by rainfall intensity, soil property, wind, temperature and land cover (Larionov *et al*., 2014; Nciizah*et al*., 2015). The physical process based Water Erosion Prediction Project (WEPP) model has been used to provide insights of the mechanisms driving the erosion processes (Dun *et al*., 2009; Laflen *et al*., 1991); the model has been applied in regions of different scales (Mahmoodabadi *et al*., 2013). Singh *et al.* (2011) calibrated and validated the WEPP model using field-measured data, and the results showed that the WEPP model could simulate runoff and sediment yield satisfactorily in the eastern Himalaya, where high rainfall and steep slopes exist. Pandey *et al.* (2008) reported that the WEPP model was successfully used in the upper Damodar Valley, India. Some researchers have explored the potential use of WEPP model in China from different aspects. For example, Lei *et al.* (2001, 2002) simulated rill bed erosion with WEPP based on an experimental study using disturbed soils from the Loess Plateau in Shaanxi, China. They found that the sediment content in runoff had great impact on soil detachment rate, and small changes in erosion parameters had a large impact on the simulation results. Studies by Zhang *et al.* (2005) concluded that lacking of a reasonable theoretical analysis and strict mathematical deduction limited the application of the WEPP model.

Shen *et al.* (2009) calibrated the WEPP model using measured daily runoff and sediment yield over two years, and they reported that the WEPP model predicted reasonable runoff and sediment yield in a watershed with variable land-uses. Rachman *et al.* (2008) used the WEPP model for a small watershed at a stiff-stemmed grass hedge system; they calibrated the model with two year measured data and found that, the simulated runoff and sediment yields were in good agreement with the observations. Most of the studies mentioned above were conducted over watershed scale. Because of the complex nature of land uses in different watershed, modelling results obtained from one place may not be true in another place. Even more, modelling study on a watershed scale may sometimes result in internal errors that offset each other for different land-use types and slope conditions. Such problems may leave out the important processes of soil erosion and cause cumulative errors in model predictions. Therefore, it is important to test a soil erosion model such as WEPP on a single slope where runoff and soil losses are observed specifically.

In this paper, we present a model testing study that applied the WEPP model on a small gully in the Loess Plateau of China using 5-year monitoring data collected from an erosion experimental station. We prepared the model input parameters based on the available data in order to provide a model testing approach through a rather free-of-calibration procedure. The goal is to evaluate whether WEPP can be efficiently used in such regions to predict runoff events, volumes and sediment yields.

MATERIALS AND METHODS

Site description and data collection**:** Figure 1 shows the location of study area at the Baota District of Yan'an City in Shaanxi, China (E109°18'45"- 109°26'15", N36°32'30"- 36°35'00"). The annual temperature ranges from 6 to 10℃ and the annual precipitation from 300 to 500 mm from south to north (An *et al*., 2005; Li *et al*., 2002).

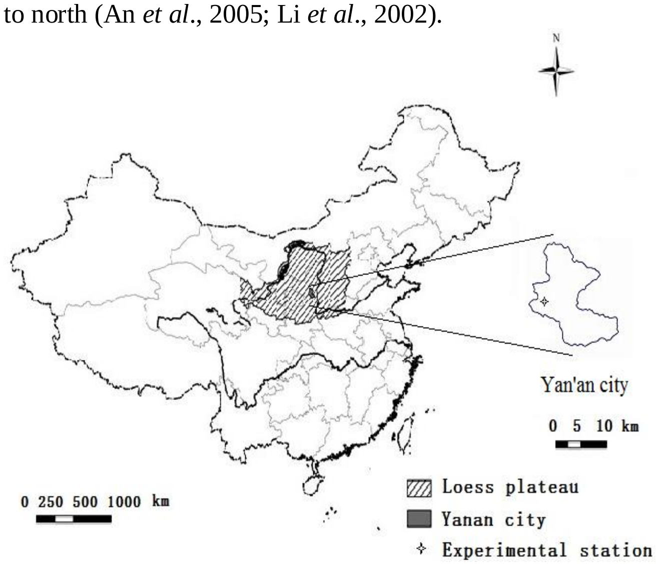


Figure 1. Location of the experimental site.

The area has a typical loess soil that has a very uniform texture. From 1998 to 2002, a monitoring study on soil erosion was conducted on slope plots for three treatments: 1) Managed grass (Grass), 2) Corn planted along contoured furrow (Corn), and 3) Bare surface (Bare). Detailed storm events, runoff and sediment were measured in each storm events, and soil water contents were measured every ten days on 5^{th}, 15^{th} and 25^{th} of each month.

Model inputs**:** The Water Erosion Prediction Project (WEPP) is a physically based erosion prediction model. It predicts runoff and soil losses over a spatial and temporal distribution on an event or continuous basis at different scales. The model input parameters include four parts: topography (slope), soil, climate, and management (vegetation) (Chaves and Nearing, 1991). The physical properties of the three testing plots are summarized in the Table 1, including grass, bare and corn. The depth of tillage for corn was 25-30 cm. We monitored rainfall depth, rainfall duration and the temperature of each storm event onsite.

Table 1. Physical properties of the three treatment plots.

	Grass plot	Corn plot	Bare plot
Slope (°)	29	20	15
Orientation	NW	NW	WN
Slope length (m)	45.7	21.3	20.7
Area (m^2)	228.7	106.4	103.5
Soil	Yellow loam	Yellow loam	Yellow loam
Land cover	Managed grass	Furrow corn	Bare

Other climate data including wind speed and solar radiation were generated by CLIGEN. The soil type of the three plots are yellow loam, and the soil distribution is very uniform as the same as in the Loess Plateau area. Two soil profiles were selected from each plot, and analyzed the soil property. The soil index of each sampling point was relatively close for their uniform distribution. So I used the average values of soil property at different depths. The specific soil data were listed in Table 2. The organic matter of the surface tillage layer is lower than 0.5%, and Cation Exchange Capacity (CEC) is generally lower than 10 meq/100g. Low CEC is indicative of sandy texture soil and prone to cause soil loss.

Model evaluation**:** Model performance was evaluated both qualitatively and quantitatively. The qualitative evaluation was to show how many recorded runoff and sediment producing events were successfully predicted by the model, while the quantitative evaluation was to compare the

Table 2. Soil input parameters used in the WEPP model simulation.

Soil depth (cm)	Organic matter (%)	CEC (meq/100g)	Particle composition (%) Particle distribution (mm)				
			1—0.05	0.05—0.01	0.01—0.005	0.005—0.001	<0.001
01—12	0.48	6.61	25.3	46.9	5.7	14.7	7.4
12—36	0.44	9.78	29.1	43.4	7.6	13.5	6.4
36—55	0.29	—	28.8	43.7	7.3	12.8	7.4
55—84	0.23	—	30.2	45.5	6.3	11.6	6.4
84—150	0.24	—	—	—	—	—	—

agreement between the measured and the predicted runoff volumes and sediment yields. The relative error, the correlation coefficient and the Nash-Sutcliffe modelling efficiency were used for quantitative evaluation of the WEPP model predictions.

The relative error (R_e) is calculated as:

$$R_e = \frac{Q_{mi} - Q_{pi}}{Q_{mi}} \cdot 100\% \quad (1)$$

Where Q_{mi} is the measured value for event i, and Q_{pi} is the predicted value for event i .

The correlation coefficient (r) is calculated as :

$$r = \frac{\sum_{i=1}^{n}(Q_{mi} - \overline{Q_{mi}}) \cdot (Q_{pi} - \overline{Q_{pi}})}{\sqrt{\sum_{i=1}^{n}(Q_{mi} - \overline{Q}_{mi})^2 \cdot \sum_{i=1}^{n}(Q_{pi} - \overline{Q}_{pi})^2}} \quad (2)$$

Where $\overline{Q}_{mi}$ is the measured average value, and the $\overline{Q}_{pi}$ is the predicted average value for event i.

The Nash-Sutcliffe modelling efficiency (η) is calculated as:

$$\eta = 1 - \frac{\sum_{i=1}^{n}(Q_{mi} - Q_{pi})^2}{\sum_{i=1}^{n}(Q_{mi} - \overline{Q}_{mi})^2} \quad (3)$$

RESULTS AND DISCUSSION

***Measured and predicted events*:** In the 5-year monitoring period (1998-2002), there were 19 recorded storms that produced measurable runoff at least on one of the plots. The maximum rainfall depth was 81.5 mm, the minimum was 10.9 mm, and the average was 30.3 mm. The storm events were not evenly distributed in the 5 year monitoring period: there were 11 events in 1998, 2 in 1999, 3 in 2001 and 3 in 2002. The recorded rainfall depths during the monitoring period (1998 to 2002) are shown in Figure 2. Nearly half of the rainfall events (8 events) were between 10 to 20 mm; 5 events (26%) were in the range of 20-30 mm; only 3 events were greater than 50 mm.

Table 3 lists the number of measured and predicted events that produced runoff and sediment for all three plots. "N_m" denotes the number of measured runoff and sediment-producing events in the year; and "N_i" is the number of simulated runoff and sediment-producing events in the year. In the grass plot, runoff observed in 8 storm events, and 5 of them were predicted by WEPP. In the corn plot, the observed runoff-producing events were 10, but only 5 were predicted by WEPP. In the bare plot, the observed runoff-producing events were 19 while 12 were predicted by WEPP. Because the premise for sediments yield is storm runoff, the WEPP predictions of runoff events affected the predictions of sediment yield in the experimental plots. As listed in Table 3, the model consistently under predicted the sediment-producing events; the observed and the predicted sediment events were 8 and 5 in the grass plot, 9 and 3 in the corn plot, 17 and 12 in the bare plot, respectively. The greater number of runoff and sediment events in the bare plot were not only contributed by the management scheme, but also by the fact that the bare plot has the shortest slope length of 20 m.

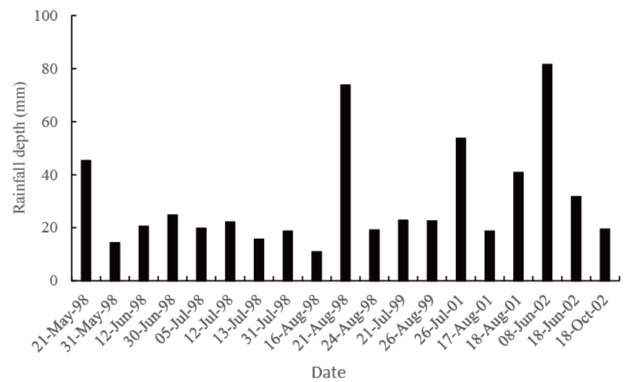


Figure 2. Rainfall depth during the monitoring period (1998 to 2002).

During the monitoring period, the storm events were mostly concentrated in 1998 and 2002. On the annual basis, there were totally 22 runoff-producing events were observed in 1998 from all three plots, while 13 (59.1%) of them were

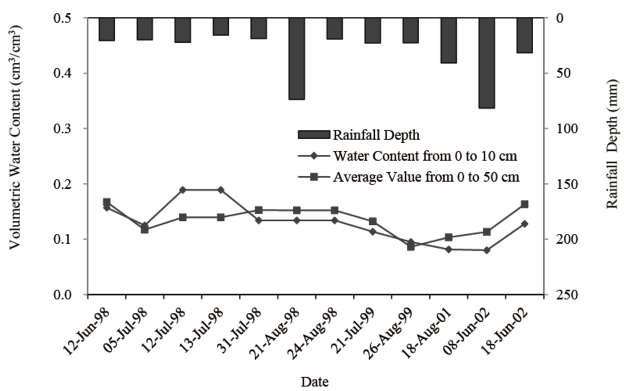
Table 3. Measured and predicted number of runoff and sediment yielding events.

	Plots	Plot 1 Grass plot		Plot 2 Corn plot		Plot 3 Bare plot		Annual total	
		N_m	N_i	N_m	N_i	N_m	N_i	N_m	N_i
Runoff	1998	5	3	6	3	11	7	22	13
	1999	1	1	2	1	2	2	5	4
	2000	0	0	0	0	0	0	0	0
	2001	0	0	0	0	3	1	3	1
	2002	2	1	2	1	3	2	7	4
	Total	8	5	10	5	19	12	37	22
Sediment	1998	5	3	5	1	9	7	19	11
	1999	1	1	2	1	2	2	5	4
	2000	0	0	0	0	0	0	0	0
	2001	0	0	0	0	3	1	3	1
	2002	2	1	2	1	3	2	7	4
	Total	8	5	9	3	17	12	34	20

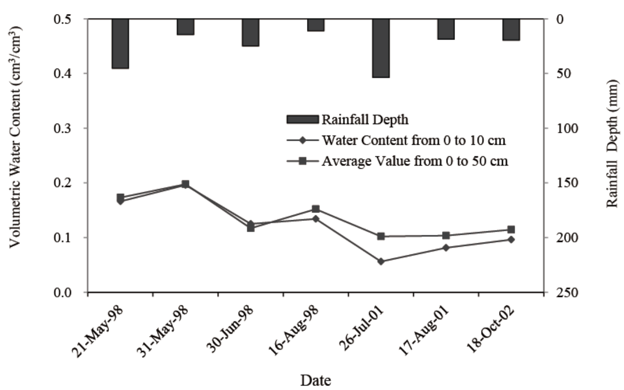
Note: N_m is the number of measured events, N_i is the number of predicted events.

predicted by the WEPP model; the predicted sediments-producing events was 57.9% of the total observed in 1998. For 2002, 7 runoff-producing events were observed, while 4 (57.1%) of them were predicted by the model, the predicted sediments-producing events was 57.1% of the total observed in 2002. The predicted runoff and sediments-producing events were less than 71% of the observed events. The number of observed runoff-producing events increased as the land cover changed from “grass” to “corn” then to “bare” surface.

Correct prediction of the runoff events depends on several factors, including the precedent soil moisture conditions. Figure 3 shows measured soil water content in bare plot changing with time during the period when the runoff-producing events were and were not predicted by WEPP model. Theoretically, runoff is more likely to form when the soil water content is higher; but the results showed different pattern. The water content during the time period when the runoff-producing events were predicted ranged from 0.08 to 0.19, while the water content during the time period when the runoff-producing events were not predicted ranged from 0.06 to 0.20. In both cases, the soil water contents had little differences.



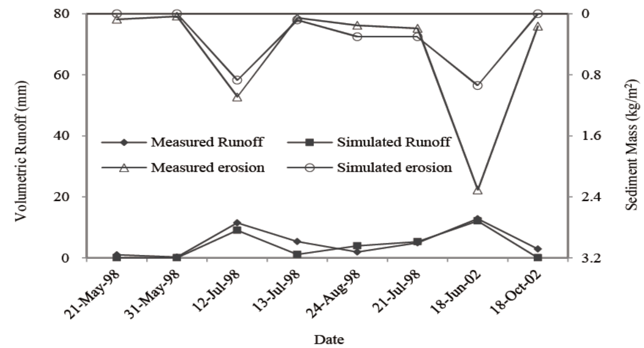
a-Predicted



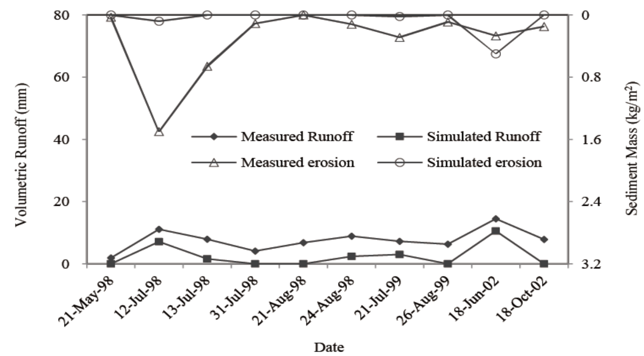
b-Not predicted

Figure 3. Soil water content changing with time when the runoff-producing events were a) predicted or b) not predicted by the WEPP model.

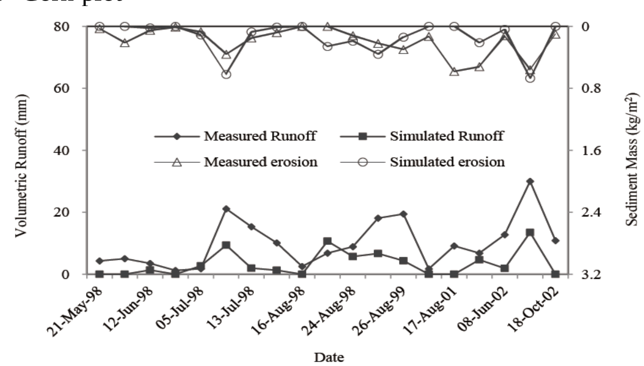
***Predicted and monitored runoff depth and sediment yield*:** Figure 4 shows comparisons of the simulated and observed runoff and sediment values for all events, and Table 4 lists the summaries of statistics data. The correlation coefficients between the observed runoff and the WEPP predictions ranged from 0.69 to 0.91, indicating generally good performance of WEPP prediction. For sediment, however, the relationship between predicted and measured values is poor, the correlation coefficient was 0.90 for managed grass, 0.52 for bare soil, and 0.11 for corn. Because some measured events were not predicted by the model, the MRE values were greater than 50% in all three treatment plots.



a - Grass plot



b- Corn plot



c - Bare plot

Figure 4. The comparison of simulated and measured runoff and sediment.

Table 4. Summary of the statistics data.

	Runoff			Sediment		
	CC	MRE (%)	Nash–Sutcliffe coefficient	CC	MRE (%)	Nash–Sutcliffe coefficient
Grass land	0.91	65.50	0.76	0.90	74.67	0.56
Corn land	0.87	77.49	-1.80	0.11	97.3	-0.41
Bare land	0.69	135.3	-0.30	0.52	76.39	-0.13

Note: CC is the correlation coefficient, and MRE is the mean relative error.

Under the managed grass cover condition, the model predictions of runoff and sediment both agreed well with the observations. This may be in accordance with some natural physical condition in that region. The Loess Plateau of China has the most damaged ecosystem in the world due to over farming and grazing practice. The average precipitation ranges from 300 mm in the southeast to 500 mm in the northwest. Historical records showed that lavish vegetation once existed and forest covered the mountainous area. But the fast growing populations in recent centuries resulted in severe damage to the vegetation. To reverse the trend, soil conservation measures have been widely advocated in recent years in these regions by means of converting farmland to grassland and keeping sheep and goats away from grazing on the sparsely vegetated areas. As a result, many areas have seen dramatic improvement in vegetation cover. The good agreement between model predictions and the field observations for the grass plot may be the result of less disturbances. In contrast, the experimental treatments with corn and bare soil surface had more disturbances that may not be properly predicted by the model.

Table 4 depicts the Nash-Sutcliffe based modelling efficiency computed on event basis. The predicted surface runoff and sediment were close to the observations only on the grassland slope, 0.76 for runoff and 0.56 for sediment. The coefficients are negative for runoff and sediment predictions for other two plots, suggesting the predictions are no better than averages.

The model performance was also evaluated on an annual basis. Table 5 lists measured and WEPP predicted annual runoff from the three different experimental slope. Because of the low rainfall in 2001, no runoff was measured from the grass and the corn slopes; the model also predicted no runoff for these two slopes. Overall, the model prediction error for runoff (Re) ranged from 7.4 to 29.0% for the grass slope, which are relatively small comparing with that for the corn slope (Re varies from 52.8 to 78.0%) and the bare slope (58.9 to 73.5%). The volume of runoff from the grassland was the smallest of all treatments. Despite the prediction errors, weighing the relative error and the real volume of the runoff from the three treatment plots, the predicted runoff was most close to the measured value in grass plot.

Table 5 shows the measured and the predicted sediment yield values had the same pattern with the runoff from the three treatments; the model predictions were more reliable from the grass plot than other treatment plots. Considering the fact that the Loess Plateau of China has a very poor vegetation cover at present, bare surface occupied a large area, predicting runoff and soil loss with WEPP model in this area should be conducted with precautions.

***Conclusions*:** We examined the accuracy of adopting the WEPP model simulating runoff and sediment for three experimental slopes located at the Loess plateau in north-western China. Less than 71% runoff and sediments-producing events were correctly predicted from all three land cover treatments. Relatively good agreements were observed for runoff predictions with the correlation coefficient values ranging from 0.69 to 0.91. However, good agreement was not consistently observed for sediment yields, the correlation coefficient was 0.90 for managed grass, 0.52 for bare soil and 0.11 for corn plot. These results revealed that the predictions by the WEPP model were more reliable for grass land than for other treatments. Because the ecosystem of Loess Plateau in China had been damaged seriously, bare land occupied a large area, the simulated cases consist of only simple, uniformed slopes, the general landscape of the region also include deep, steep valleys cutting through loess deposit, and sometimes, those valleys can develop into dominating landscape features, and become the major contributor of sediments. Therefore, application of erosion prediction models such WEPP in this region should be conducted with precautions.

Table 5. Measured and WEPP simulated annual runoff.

Year		Grass land			Corn field			Bare surface		
		Measured	Simulated	Re (%)	Measured	Simulated	Re (%)	Measured	Simulated	Re (%)
Runoff, cm	1998	19.76	14.02	29.0	40.89	11.13	72.8	80.83	33.20	58.9
	1999	4.87	5.23	7.4	13.66	3.00	78.0	37.61	11.10	70.5
	2001	0.00	0.00	/	0.00	0.00	/	17.73	4.70	73.5
	2002	15.69	12.05	23.2	22.36	10.56	52.8	53.68	15.40	71.3
Sediment, Kg/m^2	1998	1.39	1.25	10.1	2.42	0.08	96.7	1.08	1.28	18.5
	1999	0.19	0.30	57.9	0.38	0.02	94.7	0.52	0.50	3.8
	2001	0.00	0.00	/	0.00	0.00	/	1.23	0.21	82.9
	2002	2.47	0.94	61.9	0.42	0.50	19.0	0.78	0.71	9.0

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