

Evaluation of interrill component of WEPP model for three contrasting soil types

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Abstract

Measured interrill erosion rates were compared to soil loss predicted by the proposed equations in WEPP (Water Erosion Prediction Project) in a laboratory study for three contrasting soil types from Iran. The soils used in this study were: a calcareous clay loam from a cultivated field, a well aggregated clay loam from a rainforest, and a dispersive sandy loam soil without any defined stable aggregates. Mean weight diameters (MWD) of the aggregates were 0.53, 2.04 and 0.20 mm for the three soils respectively. The soils were subjected to simulated rainfall at different rates using a 1×1×0.1 m drainable flume at different slopes.

The interrill component of the WEPP model was evaluated with and without calibration. Baseline interrill erodibility of the soil was calculated using WEPP-

recommended equations and measured soil properties, when the model was evaluated without calibration. A Jack knifing method was used for calibrating the model. The coefficients of efficiency were respectively -14.51, 0.45 and -1.49 without calibration (using soil property-based erodibility values) and 0.89, 0.94 and 0.83 using calibrated erodibility values for the three soil used. These results indicated that WEPP-recommended equations for predicting interrill erodibility using soil properties are not applicable outside their US database and therefore the model calibration is essential.

Results also showed that the model tends to under-predict the higher values of interrill erosion. Contribution of flow driven erosion processes in interrill areas especially at steep slopes and high rainfall rates in conjunction with eventual interaction between flow and rain driven processes could be the reason of this bias. Ignoring the effect of water depth on interrill erosion is probably one of the most important problems with WEPP model.

Key-words: Soil erosion; Interrill; WEPP model; Erodibility; Rainfall simulation.

1. Introduction

Soil erosion is a major problem in the world because of its severe adverse impact on land quality and productivity and on water and air quality. Soil erosion in uplands is usually divided to interrill, rill and gully erosion.

A variety of process-based soil erosion models have been developed in order to simulate and predict erosion in recent decades. The Water Erosion Prediction Project (WEPP) is one of the most famous process-based models, in which differentiation has been made between interrill and rill erosion processes in calculating soil detachment and transport (Foster et al., 1995).

In WEPP, interrill erosion rate (D_i , $\text{kg m}^{-2} \text{s}^{-1}$) is predicted as:

$$D_i = K_{iadj} I_e \sigma_{ir} SDR_{RR} F_{nozzle} \left[\frac{R_s}{W} \right] \quad (1)$$

in which K_{iadj} is adjusted interrill erodibility (kg s m^{-4}), I_e is effective rainfall intensity (m s^{-1}), σ_{ir} is the interrill runoff rate (m s^{-1}), SDR_{RR} is a sediment delivery ratio which is a function of the random roughness, the row side-slope and the interrill sediment particle size distribution, F_{nozzle} is an adjustment factor to account for sprinkler irrigation nozzle impact energy variation, R_s is the spacing of the rills (m), and W is the rill width (m).

This paper reports on the results of a study carried out in the lab using three contrasting soil types from Iran to investigate the ability of the interrill component of the WEPP model for predicting soil loss and goes further to test the underlying physical principles of the equation used in the model.

2. Materials and Methods

2.1. Soil investigated

The soils used in this study were: a calcareous clay loam from a cultivated field, a well aggregated clay loam from a rainforest, and a dispersive sandy soil (sandy loam) without any defined stable aggregates. These soil types are hereafter referred as Quin, Forest and Sandy soil respectively. Mean weight diameters (MWD) of the aggregates for the three soils were 0.53, 2.04 and 0.20 mm respectively. Some physical and chemical properties of the soils are given in table 1.

INSERT TABLE 1 ABOUT HERE

2.2. Experimental design and procedure

Soil samples were air dried and sieved using a 4.75 mm sieve. Soil was packed into the flume and raked to produce a soil bed of uniform depth with a surface as level as possible for Quin and Sandy soils. In order to reduce infiltration and to generate runoff on the Forest soil a compacted sub-layer had to be provided for experiments with this soil. Soil was spread uniformly in the flume to a depth of 8 cm, wetted to a rate of field capacity and compacted using a light weighted roller. An additional 2 cm layer of soil was then spread on the top of the compacted layer and levelled for rainfall simulation experiments. The prepared soil beds were saturated from the bottom of the flume using drainage outlet tube connected to a water reservoir during night time. Excess water was allowed to drain from the soil by gravity before the commencement of each experiment, and the drainage outlet remained open during the experiment.

Rain was applied using a rainfall simulator with a single sweeping nozzle located 4 meters above the soil surface that sprayed drops with mean diameter (volumetric D_{50}) of 1.5 mm as measured by the flour pellet method (REFERENCE). Rainfall simulation continued until a steady state condition was achieved, which depending on soil type and rainfall rate lasted between 30 to 45 minutes. Runoff rate and sediment concentration were measured during the experiments at various time intervals.

Three rainfall rates of 31, 53 and 80 mm h⁻¹ were applied on Quin soil at five different slopes (3, 5, 10, 15 and 20 percent). For the Forest soil the rain intensity were 64, 80 and 96 mm h⁻¹ on 3, 5, 10 and 15 percent slopes. For the Sandy soil one rainfall rate of 80 mm h⁻¹ was applied at five slopes of 1.5, 3, 5, 7.5 and 10 percent and two rainfall rates of 70 and 95 mm h⁻¹ at the slope of 5 percent.

2.3. Data analysis

For the specific experimental conditions of this study Equation 1 can be simplified to Equation 2.

$$D_i = K_{iadj} I_e Q_{ir} \quad (2)$$

where Q_{ir} is XXXXXXX

In this study, baseline interrill erodibility (K_{ib}) is only adjusted for slope to give K_{iadj} , i.e.:

$$K_{iadj} = K_{ib} (CK_{isl}) \quad (3)$$

where, CK_{isl} is calculated by Liebenow et al. (1990) and K_{ib} could be estimated by the proposed equation of WEPP model (Alberts et al., 1995) or obtained by calibrating the model.

In this study, Equation 2 was assessed with and without calibration. The WEPP-recommended equations (Alberts et al., 1995) were used for estimating K_{ib} using soil properties when the equation was evaluated without calibration. A Jack knifing method (Shao and Tu, 1995) was used for evaluation of the model with calibration. Thus for obtaining each data point (predicted vs. measured value), the measured values of soil loss were drawn out one by one from the data set for each soil type. Baseline interrill erodibility (K_{ib}) for a given experiment was then determined using the other measured values by optimization techniques (Blau et al., 1988; Nearing et al., 1989). The objective function used for optimization was sum square error.

3. Results

Rills did not develop in any of the experiments, thus the flow was considered as sheet and erosion type as interrill. All the data were normalized for the slope length of one meter by multiplying by $1/\cos\theta$, where θ is slope angle. After examining the changes in time runoff rate and sediment concentration, the steady state condition was defined for each experiment by averaging the three or four last measured data. Sediment concentration data were then converted to interrill erosion rate in terms of $\text{kg m}^{-2} \text{s}^{-1}$.

3.1. Evaluation of the model without calibration

Figure 1 shows the measured soil erosion values against predicted values of equation 2 without calibration for all soils investigated. In this case, the model has overpredicted interrill erosion for all three soils in the entire range of erosion. The coefficients of efficiency (Nash and Sutcliffe, 1970) were -14.51, 0.45 and -1.49 for Quin, Forest and Sandy soil respectively. The mean percentage of over prediction (calculated as $\Sigma(100.(P_i-M_i)/M_i)/n$, where P_i is predicted value, M_i is measured value, and n is the number of observation) was 346, 42 and 261 percent for Quin, Forest and Sandy soil respectively.

INSERT FIGURE 1 ABOUT HERE

3.2. Evaluation of the model with calibration

The ability of the model to predict interrill erosion enhanced to a reasonable level when it was calibrated (Fig. 2), though the model still has a tendency to overpredict the lower values of soil loss, and underpredict the higher values of soil loss (Fig. 2 a, b). In this case, the coefficients of efficiency (Nash and Sutcliffe, 1970) were 0.89, 0.94 and 0.83 for Quin, Forest and Sandy soil respectively.

INSERT FIGURE 2 ABOUT HERE

3.3. Changes with rainfall rate and slope of baseline interrill erodibility

To test some of the underlying physical principles of the model, we examined the changes of measured K_{ib} with rainfall rate and slope. The hypothesis was that if the model is based on right assumptions then the calibrated K_{ib} would not change greatly with slope and rainfall rate, but may show some random variations due to measurement error. Equations 2 and 3 were used to calculate K_{ib} for each experiment, noting that all other terms such as D_i , I_e , Q_{ir} and the slope factor are given by values adapted for this experiment. The calculated values of K_{ib} then were plotted against slope and rainfall rate for each soil type. The results (Fig. 3) show some systematic changes with rainfall rate and slope in K_{ib} . In the Quin soil (Fig. 3a), for example K_{ib} increases with slope under rainfall rate of 53 mm h^{-1} , or for Forest soil (Fig. 3b) K_{ib} increases with rainfall rate at all slopes.

INSERT FIGURE 3 ABOUT HERE

4. Discussion

The results (Fig. 1 and 2) indicated that WEPP-recommended equations for predicting interrill erodibility using soil properties may not be applicable outside their US database and therefore the model calibration is essential. Yu et al. (2000) also concluded that use of WEPP requires calibration with locally obtained data.

Results also showed that the model tends to under-predict the higher values of interrill erosion. This bias has been shown by many researchers (i.e. Risse et al., 1993; Nearing, 1998; Soto and Diaz-Fierros, 1998; Yu et al., 2000; Kinnell, 2003) for a variety of models.

Changes with slope and rainfall rate in calibrated baseline interrill erodibility show some evidence of systematic trends indicating probable structural uncertainty in the model. Structural uncertainty arises from the inadequacy and the incompleteness of the model in representing the physical system being studied (Chaves and Nearing, 1991).

The reasons for model bias and trends in calibrated baseline interrill erodibility shown in this study could be: (i) contribution of flow-driven erosion processes in interrill areas especially at steep slopes and high rainfall rates in conjunction with eventual interaction between flow and rain driven processes, (ii) ignoring the effect of water depth on interrill erosion which has been shown in many studies (i.e. Moss and Green, 1983; Ferreira and Singer, 1985; Kinnell, 1991, 1993), and or (iii) using inappropriate equation for calculating slope factor (i.e. the equation of Liebenow et al., 1990).

5. Conclusion

Interrill soil erosion rates predicted by the interrill component of WEPP model was compared with laboratory measurement on three contrasting soil types under different rainfall rates and at a range of slopes (< 20%). The model is not able to reproduce measured soil loss without calibration. Calibrated erodibility parameter improved the model performance considerably for all soils.

It seems that there is a bias and systematic error in the predictions of model even with calibration. Neglecting the dominance of flow-driven erosion on steep slopes and high rainfall rates and also ignoring the effect of water depth on interrill erosion are probably the most important problems concerning the interrill component of the WEPP model.

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Table 1- Some physical and chemical properties of the soils

Soil properties	Sand (%)	Silt (%)	Clay (%)	SP (%)	OM (%)	CaCO ₃ (%)	pH	EC (dS m ⁻¹)
Quin soil	31	31.5	37.5	54	0.9	18	7.9	0.5
Forest soil	35.5	29	35.5	80	14.0	2	7.7	0.9
Sandy soil	78	12	10	28	0.1	12	8.0	2.6

Figure Captions

Fig. 1- Plot of the measured soil erosion values against predicted values of interrill component of WEPP without calibration for Quin soil (a), Forest soil (b), and Sandy soil (c).

Fig. 2- Plot of the measured soil erosion values against predicted values of interrill component of WEPP with calibration for Quin soil (a), Forest soil (b), and Sandy soil (c).

Fig. 3- Changes with rainfall rate and slope in calibrated baseline interrill erodibility for Quin soil (a), Forest soil (b), and Sandy soil (c).

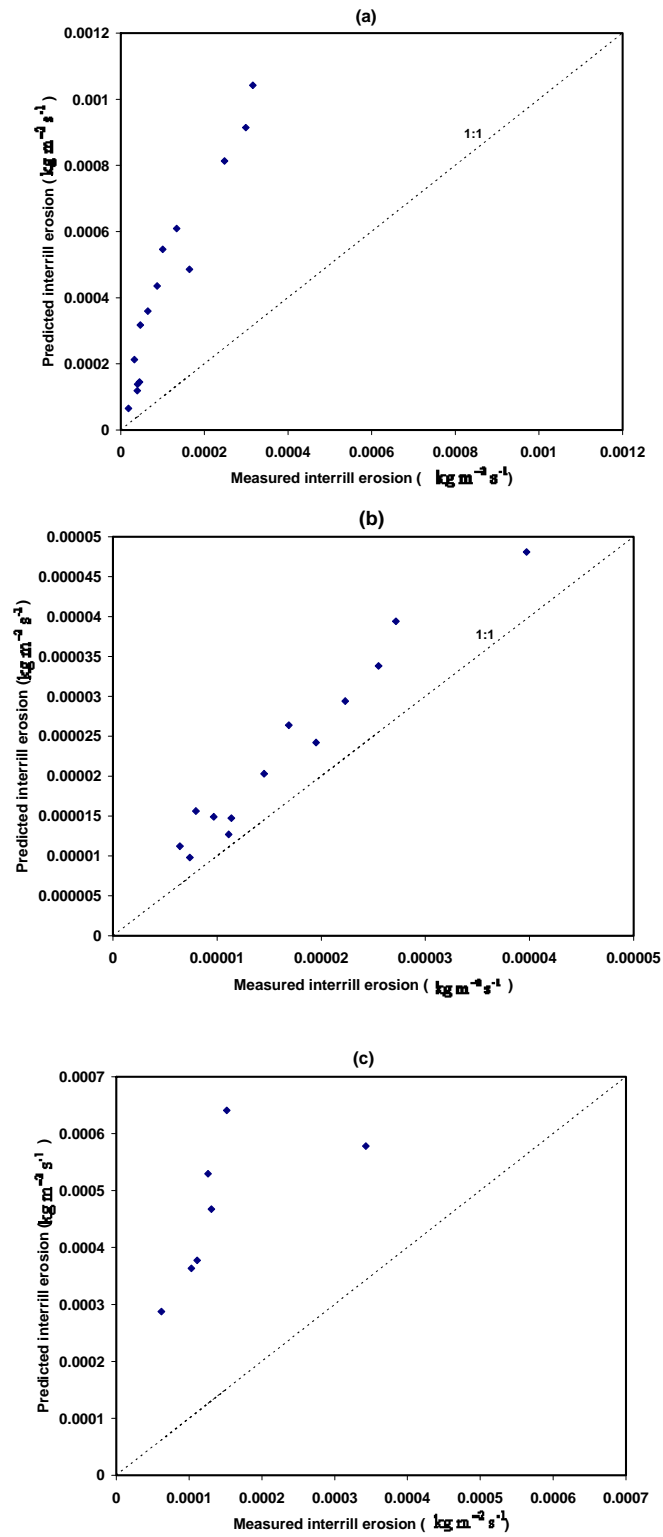


Fig. 1

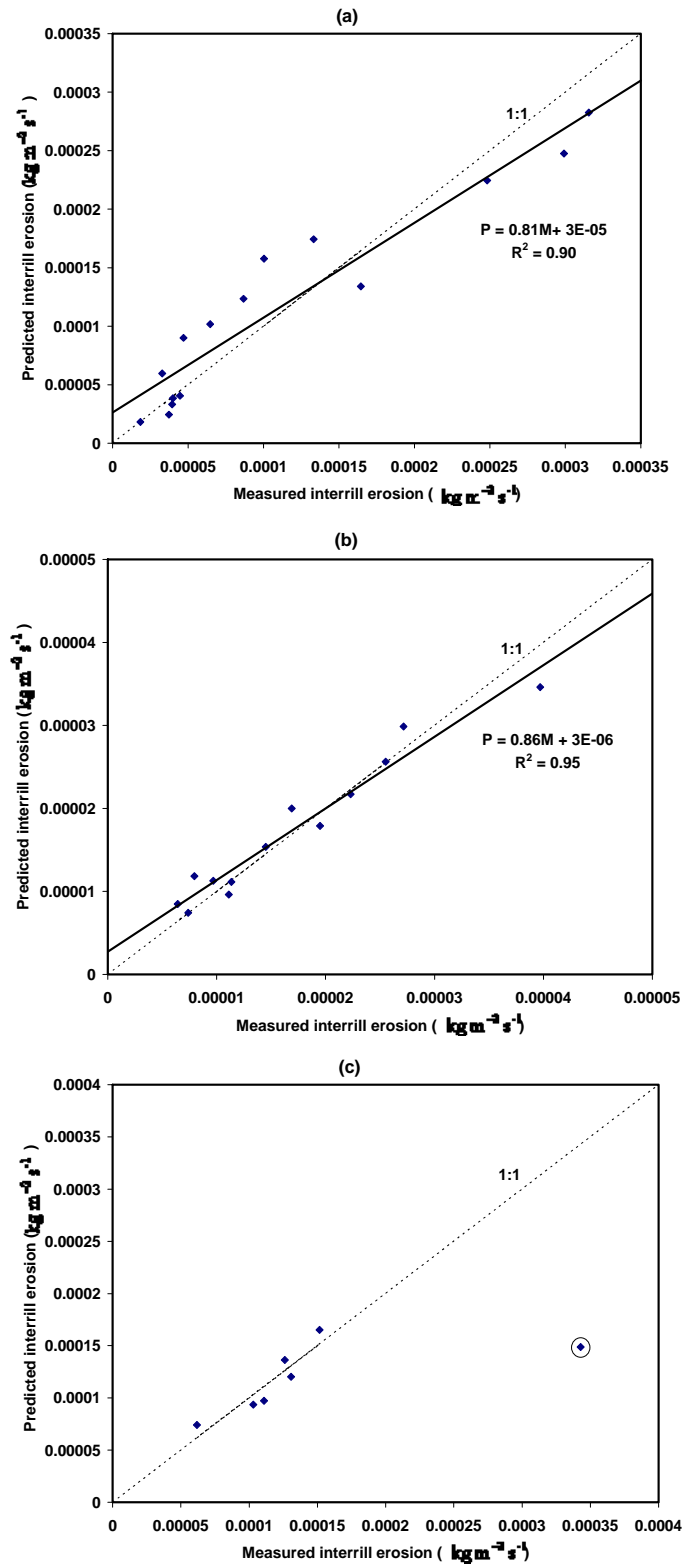


Fig. 2

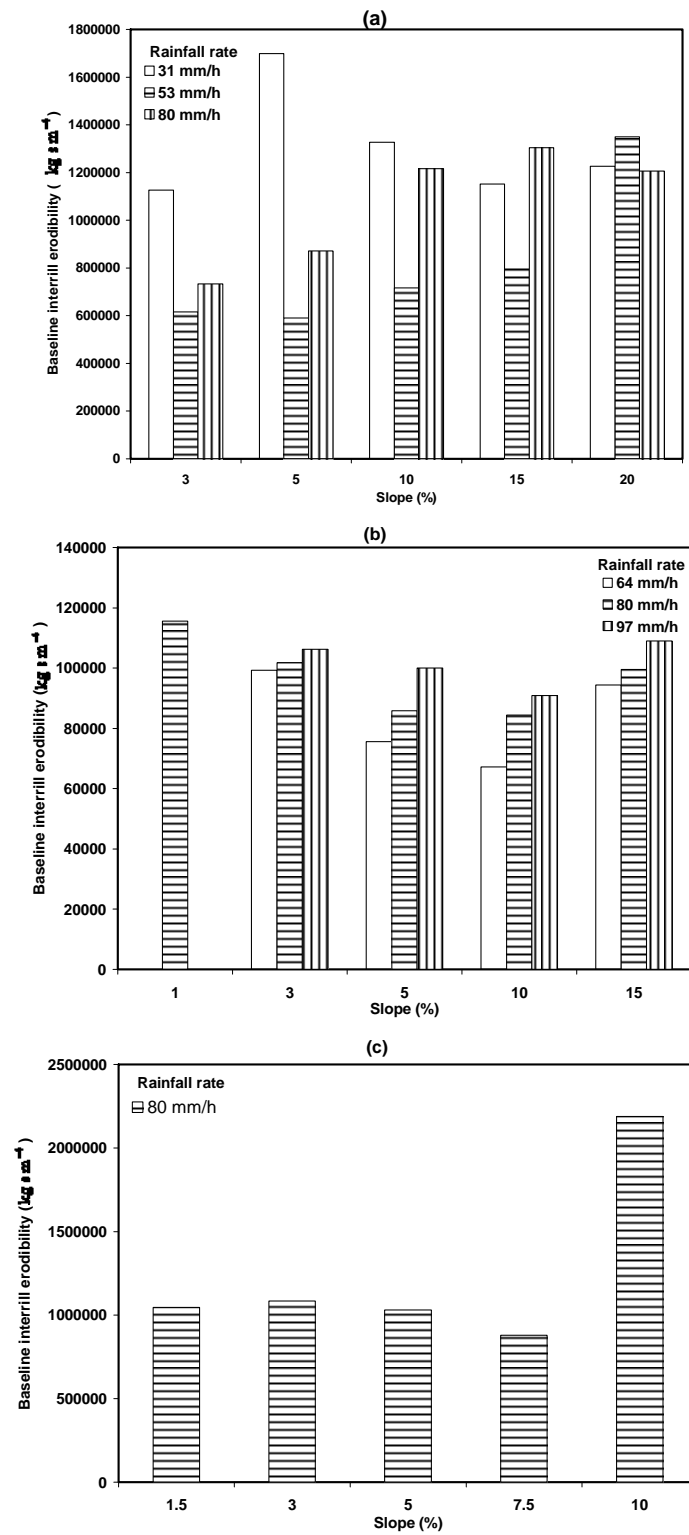


Fig. 3