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Comparison of the abilities of WEPP and the USLE-M to predict event soil loss on steep loessal slopes in China

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ABSTRACT

The need to estimate event soil loss better than the USLE and the RUSLE has led to the development of WEPP and the USLE-M, a modification of the USLE that estimates event soil loss for bare fallow runoff and soil loss plots in the USLE database better than the USLE/RUSLE when runoff is known or predicted well. Although the erosivity indices in the USLE-M and the USLE/RUSLE focus on raindrop driven erosion, the calibration of the erodibility index on plots where rilling occurs enables the USLE-M and the USLE/RUSLE to be applied on areas where sheet and rill erosion occur. This paper presents results from the application of both WEPP and the USLE-M to modelling event soil loss from 6 runoff and soil plots at the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences (36°56′N, 109°16′E) produced from steep slopes (8.7%–53.2%) where rills frequently developed under natural rainfall during 1985–1992.

WEPP was calibrated to minimize the mean squared error (*MSE*) between measured runoff and predicted runoff for the events where WEPP predicted runoff and soil loss to occur. The number of events where WEPP predicted runoff and soil loss to occur varied from 25% to 41% of events that actually produced soil loss. In the comparison with WEPP, the USLE-M erodibility factor was calibrated by dividing the total observed soil loss where WEPP predicted runoff and soil loss to occur by the total of the USLE-M erosivity factor for the same set of events. Consequently, the total amount of soil lost estimated for these events by both models were the same. This enabled the ability of the models to predict event soil loses to be examined using the Nash-Sutcliffe model efficiency index. In every case, the efficiency index values for the USLE-M were higher than for WEPP irrespective of whether the values of USLE-M erosivity index were determined using observed or WEPP predicted runoff. As a model of rainfall erosion, focusing on a process based approach has not resulted in WEPP performing as well as or better than the USLE-M on the steep bare fallow plots of loessal soil at the Ansai Research Station in China.

1. Introduction

In the middle of the twentieth century, it was recognized that a formal mathematical model for predicting variations in rainfall erosion associated with climate, soil, topography, and land management was needed as an aid to making decisions to combat soil erosion in the USA. That recognition led to the development of the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1965, 1978) which, largely through the use of the revised version (RUSLE; Renard et al., 1997), is now the most widely used soil loss prediction model in the world. The USLE/RUSLE model is designed to predict the long term (approx. 20 years) average annual soil loss and, as noted by Wischmeier (1976), was not designed to predict short term (annual, event) soil loss despite the fact that the climate factor (R) is based on the observation that event soil loss was empirically related to the product of storm rainfall (E) and the maximum 30-minute rainfall intensity (I_{30}) for runoff producing events (Wischmeier and Smith, 1958). Over time, it has been recognized that there is a need to predict soil losses on a shorter time scale. Operating at shorter time scales produces a capacity to take account of short term variations in vegetation and climate that are not possible at the time scale originally used for the USLE. Also, it has been perceived that more process based approaches are needed to meet the ever increasing needs of conservationists and environmental managers (Flanagan et al., 2007). This led to the development of the WEPP (Water Erosion Prediction Project) model (Nearing et al., 1989) which models rill erosion and interrill erosion more explicitly than in the

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Fig. 1. Recently established 20 m long plots with different slope gradients on a landscaped hillslope area at the Ansai Research Station installed to re-establish the situations used in the 1985–1992 experiments.
Photo: P.I.A. Kinnell, October 2016.

USLE/RUSLE approach.

WEPP is a daily simulation model keeping account of the hydrologic status of the land and biomass with erosion predictions being generated when runoff is predicted to occur (Laflen et al., 1997). Zhang et al. (1996) evaluated WEPP at 8 locations in the USA covering 566 plot years and 34 cropping practices. The WEPP input files for soil, slope, climate and crop management were compiled based on measured data. Runoff prediction was optimized by adjusting the effective hydraulic conductivity until the error sum of squares was minimised. The coefficients of determination (r^2) obtained for runoff for selected events were 0.77, 0.76 for annual values and 0.87 for average annual values. For measured soil loss the r^2 values were 0.36, 0.60 and 0.85 respectively. These results indicated that WEPP predicted long term soil losses better than short term losses. Later, Tiwari et al. (2000) compared WEPP with the USLE and RUSLE using sixteen hundred plot years of data from runoff and soil loss plots eroding under natural rainfall in the USA. Comparison of the associated Nash-Sutcliffe model efficiency index (Nash and Sutcliffe, 1970) values showed that WEPP performed with the same efficiency as the RUSLE but worse than the USLE in accounting for long term time soil losses. Also, WEPP performed worse than both the USLE and the RUSLE in accounting for variations in annual soil loss. Tiwari et al. argued that this results could be attributed to the availability of more refined and site specific inputs parameter values for the empirical models given that WEPP had not been calibrated for this exercise on any of the plots. According to Flanagan et al. (2012), the result obtained by Tiwari et al. indicated that using WEPP in place of the USLE and the RUSLE was quite acceptable.

While it has been argued that WEPP performs at levels similar to both the USLE and the RUSLE in terms of prediction average annual soil loss, as noted above, USLE based technology does have the capacity to predict event soil loss because it is based on the assumption that event soil loss is directly related to the product of event storm kinetic energy (E) and the maximum 30-minute intensity (I_{30}) for runoff producing events (Wischmeier and Smith, 1958). Consequently, the USLE/RUSLE model can be used to model soil loss in the short term. Also, although RUSLE2 (Foster et al., 2001; USDA, 2008) operates on a daily time step to better predict long term soil loss, it has the capacity to predict soil loss associated with individual erosion events (Dabney et al., 2011). This has enabled the USLE-M (Kinnell and Risse, 1998) to be applied to predict event erosion within RUSLE2 (Kinnell, 2014). The USLE-M uses the product of the runoff ratio and EI_{30} as the event erosivity index and has the capacity to predict event soil loss from bare fallow areas better than the RUSLE when event runoff from runoff and soil loss plots in the USLE database is known (Kinnell and Risse, 1998) or predicted well. It has also be shown that the USLE-M has the capacity to predict event soil losses better than WEPP on bare fallow runoff and soil loss plots in the USA with slopes up to 18% (Kinnell, 2017). However, to date, no comparison has been made of the ability of WEPP and the USLE-M to model soil loss produced by individual natural rainfall events on high slope gradients like those that occur on the Loess Plateau in China. Rill erosion is common on these slopes and given that WEPP is designed specifically to model rill erosion, arguably WEPP should predict event soil losses on these slopes better that the USLE-M. In order to examine this, the USLE-M and WEPP were applied to modelling event soil loss from runoff and soil plots at the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Sciences (36°56′N, 109°16′E) produced from steep slopes (8.7%–53.2%) under natural rainfall during 1985–1992. Given that the USLE/RUSLE model is the most widely used erosion prediction model in the world, a comparison between the USLE-M and the USLE/RUSLE models is also presented.

2. Materials and methods

A hillslope at the Ansai Research Station was landscaped to produce 6 plots with different gradients (8.7%, 17.6%, 26.8%, 36.4%, 46.6%, 53.2%) adjacent to each other. Each plot was 20 m long, 5 m wide and was maintained in continuous bare fallow under conventional tillage. The soil was turned over with a spade to about 0.2 m deep in mid-April each year. Rill erosion frequently occurred on the plots. Manual tillage was also used to eliminate rills between storms. The soils contained 19% sand, 70.3% silt and 10.7% clay (Liu et al., 2000). The runoff containing eroded soil from the plots was collected in 2 tanks at the bottom of the plots, a slot devisor used to split off a sample of the overflow from the first tank into the second (Jones and Despain, 1995). Some years later, the plots were abandoned but the experiments have been recently re-established (see Fig. 1). The particle size data for the new plots show no appreciable differences between the plots. Although soil erodibility may not have varied between the plots in the 1985–1992 experiments, the plots were treated as if they were separate individuals in respect to calibrations performed here.

Generally, erosive rainfall was restricted to the May to October rainy season that occurs in the area. 68 events producing soil loss from